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USES OF WATER IN THE OIL-SHALE INDUSTRY

WITH PARTICULAR REFERENCE TO ENGINEERING REQUIREMENTS

BY

J. J. JAKOSKY

WITH A CHAPTER ON

THE SANITATION OF OIL-SHALE CAMPS

BY

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WASHINGTON
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PREFACE.

Although oil shales are widely distributed throughout the United States, particular attention has been and still is being directed to the large and rich deposits in the States of Colorado, Utah, and Wyoming. Recently, more attention has been paid to shales of generally lower grade east of the Mississippi River, for it is being appreciated that though these shales may yield less oil per unit there are other considerations, such as greater ease and cheapness of mining, that tend in considerable measure to offset low yield of oil.

This paper, prepared in cooperation with the department of metallurgical research of the University of Utah, treats of the uses of water in the oil-shale industry primarily from the standpoint of one interested in the shales of the Rocky Mountain district. However, many of the considerations developed apply equally well to oil-shale operations elsewhere.

Any engineer making a trip through the oil-shale region of the Rocky Mountain country will be struck by the fact that the water-supply problem will have to be solved before an oil-shale industry of any considerable size can be started there. The situation does not appear so serious to those who do not travel far from the main streams or arteries of travel, although even in these places it may cause thought. Only when one gets away from the railroads—and often that means visiting the richer deposits—does the magnitude of the water-supply problem become fully evident. There are few large watercourses, and these are generally far apart. Many of the smaller tributaries are periodic; they may be entirely dry part of the year but roaring torrents during the rainy months. Little is known as to possibilities of obtaining adequate water supplies by well drilling, but in many places the prospects do not look very favorable.

Those deposits situated on the main watercourses may seem to be adequately supplied, or so situated that they may be adequately supplied, with water for development or production work. The reader must bear in mind, however, that much of the water of these streams is already appropriated for agricultural or other uses, perhaps lower down on the stream, and that the amount of such appropriation may increase, as agricultural demands ordinarily take legal precedence over industrial requirements.

Each prospective oil-shale operator, especially in the western part of the country, must ask himself, "How is my property situated with regard to adequate water supply; have I, or can I obtain, enough for my plant requirements and the domestic uses of my employees?"

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Each plant and every location must be considered a separate problem. The type of plant, nature of products made, scale of operations, future expansion, and related items, will all have important bearing on the question. Consequently, this paper does not pretend to go into great detail as to any one set of conditions, but points out what factors must be considered and suggests methods by which they may perhaps be considered most advantageously. Data relative to Scottish oil-shale operations have been drawn on freely, as Scottish practice is the only existing commercial oil-shale practice. If the importance of domestic water supply has been emphasized, it is because it deserves very great consideration and because it has often been nearly ignored in industrial plant operations. The same statement applies to the relatively large part of the paper devoted to sanitation and sanitary requirements.

The oil-shale industry of the United States probably has a great future. It is unique in that it may be developed from more or less basic and predetermined considerations. Among the many fundamental problems that must at least be partly solved before the industry can grow to commercial magnitude is water supply. Those contemplating plant development are urged to study this problem carefully; by doing so they will avoid future expenditures and legal controversies.

MARTIN J. GAVIN,
Oil-Shale Technologist.

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USES OF WATER IN THE OIL-SHALE INDUSTRY, WITH PARTICULAR REFERENCE TO ENGINEERING AND SANITARY REQUIREMENTS.

By J. J. JAKOSKY.

INTRODUCTION.

The increasing demand for petroleum and its products has drawn attention during the past few years to the oil-shale deposits of the United States. Up to 1922, a number of experimental and semi-commercial plants had been erected and some quantities of crude shale oil recovered. Water is now and will be required in practically all of the shale plants, yet little information has been published regarding its uses and the estimated quantities required for an oil-shale industry. Engineers engaged in preliminary plant designs have had little data for making estimates for water supply.

At the present stage of the shale industry in this country it is almost impossible to state definitely the amount of water required for large-scale operations. The amount required for mining and crushing the shale will probably be similar to that in the coal-mining industry where similar conditions exist. The per capita domestic requirements for water will vary with the location of the plant and with local conditions. The most important use for water is in retorting and refining, but the amount that will be required for these purposes is more in doubt than that for power or domestic use.

No standard retorting or refining practice for oil shale and shale oil has yet been established in the United States. Many retorting processes have been proposed, and perhaps 25 or 30 experimental or demonstration plants have been erected in different parts of the country. Practically without exception, however, these plants are too small to be considered as commercial, or to give operating data that would be of much value in estimating water requirements.

The proposed retorts for treating oil shale may be grouped in a general way under two heads: (1) Those in which dry destructive distillation takes place, and (2) those in which distillation progresses in the presence of superheated steam or gas. In the well-known Scottish type of retort, used for many years in Scotland, steam is used. Whether or not Scottish practice will be followed in this country remains to be seen, but as the Scottish plants are to-day the only ones

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operating on a large commercial scale, knowledge of their water requirements will be of value in estimating requirements for plants in the United States. If, later on, American retorts should be designed differently so that they use less water or none at all this development will in many cases be a point decidedly in their favor.

It should be made clear, however, that shale retorting and refining plants will require water, whether or not the retorts are steamed. Large quantities of water will be needed for power, mining, and domestic uses. The oil vapors must be condensed, the distillates treated, and the fixed gases scrubbed; and in other stages of retorting and refining there are many uses for water. Yet even now, large oil-shale plants are being proposed in regions where the water requirements, if only for mining and domestic use, will present a problem that may require the expenditure of considerable technical ability and capital for ultimate solution.

The purpose of this paper is to point out the uses of water and to estimate the water requirements in the production of shale oil. Because of the infancy of the oil-shale industry in this country, attention has been directed, in the latter part of the paper, to community and camp sanitation; also effort has been made to prevent, as far as possible, a repetition of some of the errors made in large industrial communities in the past.

ACKNOWLEDGMENTS.

The writer desires to thank M. J. Gavin, oil-shale technologist of the U. S. Bureau of Mines, for cooperation and assistance in the preparation of this paper; and Thomas Varley, superintendent of the Intermountain experiment station of the Bureau of Mines, for aid and suggestions in the compilation of the data on mining.

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Particular thanks are due various companies and individuals for their cooperation in supplying data, analyses, etc. Effort has been made to acknowledge such help at the proper place in the paper.

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USES FOR WATER.

The production of marketable products from oil shale may be divided into three stages: Mining, retorting, and refining. If in addition ammonia or other nitrogenous products are made, there may be a fourth stage, in which these products are finished for the market. All these operations require water. In addition, water for domestic use by the plant employees and also for the inhabitants of the plant community must be supplied, and the amount may be even greater than that required by the industry itself.

MINING.

By far the largest part of the water used in mining oil shale is that consumed in the production of steam for power. In addition, water may be required for humidifying the mine atmosphere, to lay the dust, and lessen the danger of dust explosions. It is probable that oil-shale mining in any one part of the United States will be similar, in general, to coal mining in the same general locality, and for that reason considerable emphasis is directed to the power and water requirements of western coal mines. (See pages 13 to 19.) Before these factors are discussed, however, it may be well to describe briefly oil-shale mining and shale-oil production and refining as they are conducted in Scotland.

SCOTTISH OIL-SHALE MINING METHODS.

Various mining methods are employed in Scotland for mining, but the most prevalent method at present is the room-and-pillar and retreating system. The main drifts are driven and pillars are left. As conditions during this stage of the mining may determine, from 15 to 25 per cent of the oil shale is taken out. After the mining has been carried to previously determined boundaries, the retreating system is followed and the blocks or pillars are removed. The pillars are divided into four blocks or sections and these are mined in order. In this method of mining, the loss or amount of shale left underground, including fines and poor shale, is about 25 per cent.

In mining the shale, hand augers (1¾ inches and then 1½ inches) are used for drilling and black powder for shooting. The mining is done by contract between the operating company and the miner, with a guarantee of a minimum daily wage; each miner employs his own men and provides their tools, supplies, and powder. The miner loads the shale on the cars and delivers it to the nearest main haulageway; the company hoists the shale to the surface and handles it from that point on. The average amount of shale mined daily per man working at the face is 4½ to 4¾ tons. Usually two men work together, one man mining and the other mucking and tramming,

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and the two will usually mine about 9 to 9½ tons of shale a day. Where conditions are such that two miners and one trammer can work together advantageously, about 14 tons of shale a day can be removed by the three.

In Scotland the shale mines are subject to the same laws and regulations as coal mines, and it seems likely that American shale mines also will be subject to regulations much like those controlling coal mining in this country.

RETORTING.

GENERAL CONSTRUCTION OF SCOTTISH RETORT.

In Scotland, large quantities of steam are used in retorting shale, but accurate data are not available regarding the percentage of the steam decomposed during its passage through the retorts.

The modern Scottish retorts are all of one general type, the main points of difference between those used in different plants being in the shape of the cross section of the retort and the means used for discharging the spent shale from the bottom of the retorts. Space will not permit a complete description of the Scottish retorts, but, briefly, they are vertical and consist in descending order, of (1) a fresh shale hopper attached to (2) a cast-iron retort, which is 14 feet high and tapered, being smaller at the top than the bottom. At the juncture of the hopper and the iron retort a vapor-discharge line, protected by a lip to prevent its being clogged with shale, leads to the vapor main. The iron retort is usually round or oval in cross section and is, if round, 2 feet in diameter at the top and 2 feet 4 inches at the bottom. At the bottom of the iron part of the retort it is joined to (3) a brick part, also vertical and tapered, and made of a single tier of specially shaped fire brick. The joint between the iron and brick parts of the retort is made of a special kind of fire clay, and in operation considerable care must be exercised in firing, to prevent the joint from pulling apart or cracking. The brick part of the retort may be rectangular or round in cross section. If round, the diameter at the bottom is about 3 feet; usually the height of the brick part is about 20 feet.

Below the brick part, and attached to it, is (4) the spent-shale discharge mechanism, which differs in different types of retorts. In one type of retort the discharge apparatus is a pair of toothed cast-iron rolls, which rotate slowly toward each other, and drag the spent shale from the retort. The discharge mechanism in a more commonly used retort consists of a flat iron plate on which the shale column in the retort rests, while a curved arm moves slowly over the plate and forces the spent shale from the plate as the arm rotates. The arm is operated by a shaft passing through the plate and actuated by a system of ratchets and pawls, as are also the other types of discharge mechanism, the motion of the lever arms driving the ratchet wheels, and thereby the rate of discharge, being controllable at will.

The discharge mechanism drops the shale into (5) the spent-shale hopper, into which exhaust steam is passed, and as the hoppers fill, the spent shale is discharged into cars which carry it to spent-shale dumps or bings. No practical use has ever been found for spent shale in Scotland.

Shale feeds continually from the fresh-shale hopper into the cast-iron part of the retort, and in this part the bulk of the oil is distilled, at a temperature of about 900° F. Descending, the shale, in the brick part of the retort, gradually heats up until at the bottom of the retort its temperature may reach 1,500° to 1,800° F.[1]

[1] Gavin, Martin J., The past, present, and future of the oil-shale industry: California Oil World, vol. 13, May 26, 1921, second section, pp. 84–85.

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FUNCTION OF STEAM IN THE RETORTING PROCESS.

The exact chemical rôle of the steam in increasing ammonia recovery, and the reason for its effect on quality and quantity of oil yield is not definitely known. However, the following functions of steam in the Scottish retorts are fairly definitely established and agreed upon: (1) To reduce the temperature of the spent shale at the bottom of the retort, (2) to carry the heat, which has been recovered from the spent shale up into the retort, (3) to form water gas from the fixed carbon remaining in the shale, (4) to aid in the recovery of ammonia from the shale, (5) to act as a scavenger by adding greater volume to the vapors, thereby giving them a greater velocity in the retort and causing them to be swept out of the hot zone of distillation, largely preventing undue decomposition, (6) to effect lower temperature vaporization and removal of the heavier hydrocarbons, and (7) to counteract, by convection, the poor thermal conductivity of the shale, thereby allowing a better transfer of heat from the walls of the retort to the center of the shale column.

Of the purposes enumerated, the first two are important from engineering and thermodynamic considerations. Reducing the temperature of the hot spent shale just before its discharge from the retort not only simplifies the problem of design but lessens the depreciation of the mechanical discharge devices and also allows a better recovery of heat than could be obtained by the use of any practicable form of heat-exchanging device.

The use of steam to make water gas from the fixed carbon remaining in the shale may be advantageous by increasing the total yield of fuel gas without injuring the oil.

Exact data regarding the action of steam or air upon hot spent shale are not available, but the effects of each upon carbon, coal, and coke are known. The amount of carbon monoxide (CO) and hydrogen (H_2) formed from each of these substances, at a given temperature, depends largely upon the length of time the steam is in contact with them. Under similar conditions and during equal intervals of time the percentage of carbon monoxide formed from coke is less than that from charcoal, and the percentage formed from anthracite is less than that from coke. It will be noted that the surface exposed to the action of the gases is greatest in charcoal, less in coke, and least in anthracite. Where the time of contact is long enough to allow equilibrium to be reached in the reaction, the percentage of carbon monoxide is practically the same with all three—charcoal, coke, and anthracite. In shale retorts where the velocity of the gases through the hotter parts of the retort is very low, the character of the spent shale and its fixed carbon content, within certain limits, will probably not appreciably affect carbon monoxide formation.

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Figure 1 [2] shows graphically the variation in the amount of carbon monoxide formed with rise of temperature at various values of 1/t. The ordinate is the percentage of carbon monoxide in a gas initially containing 21 per cent CO_2 (air in which the oxygen has been converted quantitatively to CO_2). The abscissa is temperature in degrees centigrade. The upper curve, for which 1/t=0, represents the maximum amount of CO which could be produced from air.

The intersection of the curve for any velocity, with a given horizontal line—for example, the line for CO=20 per cent—gives the temperature required to form that amount of CO with the particular velocity. Thus, to obtain 20 per cent CO with a steam velocity of 1 foot per second (depth of bed=1 foot) will require a temperature of 1,290° C., and with a velocity of 2 feet per second, 1,355° C.

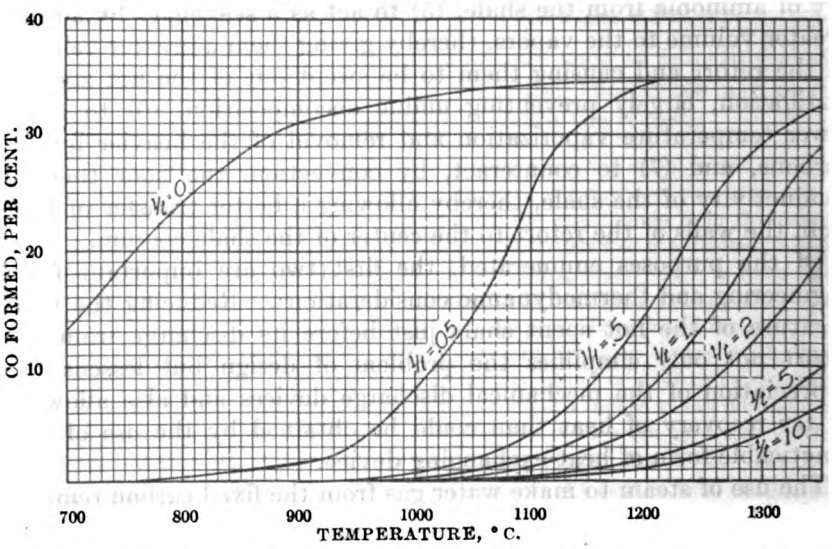

FIGURE 1.—Curves showing variation of percentage of CO formed, with rise of temperature, by the use of air and coke.

WATER-GAS GENERATION.

Carbon in an incandescent state combines readily with water vapor, forming a mixture consisting largely of carbon dioxide (CO_2), hydrogen (H_2), carbon monoxide (CO), and a small quantity of methane (CH_4).

When superheated steam is passed through incandescent carbon, the composition of the gas obtained, as well as the quantity of steam decomposed in a given time, depends largely upon the temperature of the carbon, rate of flow or time of contact of steam, and the nature of the carbon.

Harries [3] studied the action of superheated steam on carbon at high temperature by passing the vapor over incandescent charcoal and determining the constituents of the recovered gas. His work,

[2] Clement, J. K., Adams, L. H., and Haskins, C. N., Essential factors in the formation of producer gas: Bull. 7, Bureau of Mines, 1911, p. 17.

[3] Bunte, H., Zur Carburationsfrage: Jour. Gasbel., Jahrg. 37, 1894, p. 82; Haber, Fritz, Thermodynamics of technical gas reactions. London, 1908, p. 138.

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however, is of value only in giving the composition of the gas formed when steam is passed over incandescent carbon at a velocity low enough to allow equilibrium to take place. The large quantities of steam used in the Scottish shale retorts cause a velocity considerably higher than that at which equilibrium could take place. Where the steam is used mainly as a scavenging agent, its velocity will ordinarily be so great that its time of contact with the hot shale will be much shorter than that required for the equilibrium reaction.

Figure 2 is a graphic representation of the reactions between water vapor and carbon and the composition of the resulting gas. This curve was plotted from data taken largely from the table worked out by Harries.

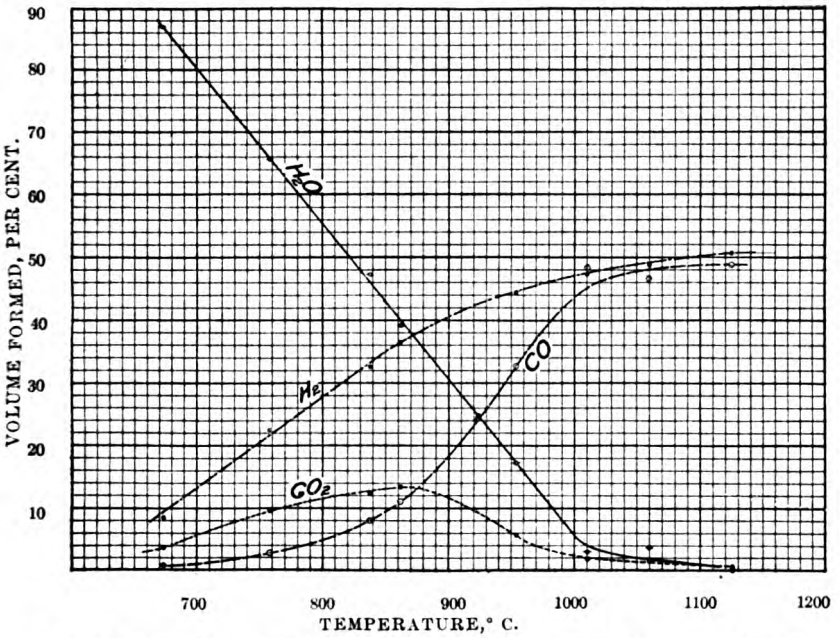

FIGURE 2.—Curves showing the composition of gas from the reaction of water vapor and carbon.

The amount of water decomposed in the presence of incandescent carbon at various temperatures is illustrated by Figure 3,[4] in which the percentage of fixed gas formed from coke and water vapor at various gas velocities is plotted as a function of the temperature. Each curve corresponds to a particular velocity or time of contact. The upper curve $l/t = 0$, was plotted from Harries's values and represents the condition of equilibrium. It shows that with infinite time of contact, or zero velocity, a temperature of 1,100° C. will be required in order for the decomposition of the water vapor to be practically complete.

[4] Clement, J. K., Adams, L. H., and Haskins, C. N., Essential factors in the formation of producer gas: Bull. 7, Bureau of Mines, 1911, p. 46.

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The reader is referred to some recent articles which contain more information relative to water-gas reactions.[5]

AMMONIA PRODUCTION.

The amount of ammonia recovered during the retorting process seems to depend almost directly, up to a certain quantity, on the amount of steam used.[6] Experiments indicate that as high as 95 per cent of the total nitrogen content of a shale can be recovered as ammonia by the use of proper amounts of steam at correct temperatures. In the Scottish retort about 60 per cent of the nitrogen in the shale is recovered as ammonium sulphate under the conditions of operation.

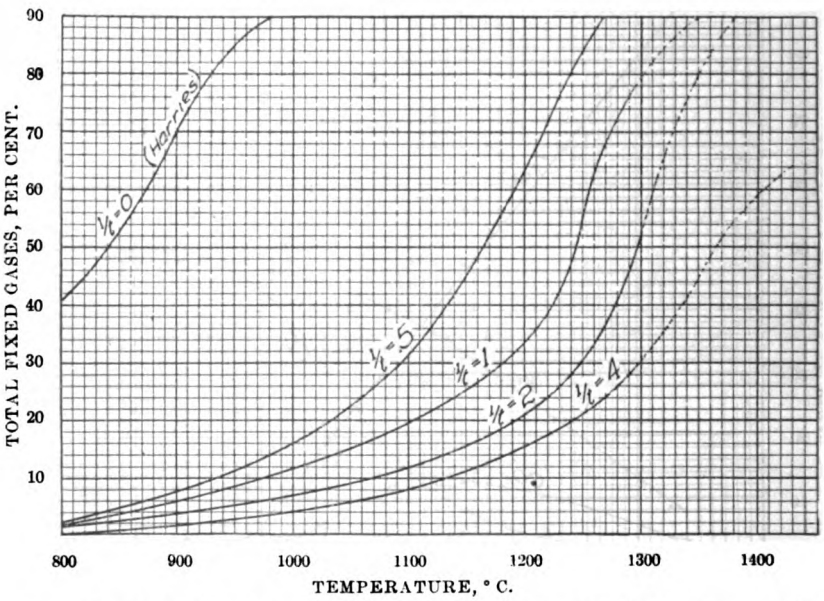

FIGURE 3.—Curves showing variation of percentage of total fixed gases formed with change of fuel-bed temperature.

STEAM AS SCAVENGING AGENT.

Present knowledge of the pyrolytic distillation of the kerogen, the source of the oil in the shale, indicates that the dead vapor space within the retort should be reduced to a minimum. Excessive decomposition or cracking may result when the vapors are allowed to stagnate or form eddy currents in hot pockets, and steam may serve as an effective preventive.

[5] Kohn, S., Contributions to the theory of water-gas process: Jour. Ind. and Eng. Chem., vol. 14, January, 1922, pp. 69–72; Rideal, E. K., Recent developments in hydrogen manufacture: Jour. Soc. Chem. Ind., vol. 40, January, 1921, pp. 13T–14T.

[6] Data from experimental work of R. D. Howard, University of Utah, Department of Metallurgical Research.

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The effect of steam in lowering the vaporizing temperatures of the heavier hydrocarbons may be of importance for the following reasons:

1. After the solid kerogen in the shale has been decomposed with the formation of liquid products, it seems highly probable that this liquid will be absorbed and adsorbed by the shale and held there by considerable pressure. G. St. J. Perrott of the Bureau of Mines, working on mixtures of coal and oil, has found it practically impossible to remove the last traces of oil even by extraction methods.

2. The temperature required for the distillation of an oil so held may be considerably above the temperature required for the distillation of the same oil when out of contact with the shale. Then steam may be advantageous in preventing cracking.

The value of steam and the amount required to counteract the poor thermal conductivity of the shale mass depends largely on the design and type of retort used. In those retorts where the shale mass is constantly agitated and mixed a much smaller amount of steam will be necessary for distributing the heat or equalizing the temperature than in those retorts where the shale mass is not mixed and all particles of shale do not receive the same heat treatment.

In retorts similar to the Scottish type previously mentioned, the shale in the center of the column will be at a lower temperature than the shale next to the hot walls of the retort. The difference in temperature will depend chiefly upon (*a*) the time of retorting, (*b*) the amount of steam or other gas used for carrying and distributing the heat by convection, (*c*) the thickness of the shale mass, and (*d*) the general character of the shale itself.

SCOTTISH REFINING PRACTICE.

The oil vapors passing from the Scottish retorts are cooled in air-cooled condensers, described on page 22, consequently no water is required in this stage. It is probable, however, that in plants in the United States water-cooled condensers for crude gases will have to replace at least a part of the air-cooled condensers used in Scottish plants. (See p. 23.) The condensed oil and water are run to separating tanks where the dust and water are allowed to separate from the oil by gravity; from these tanks the oil goes to the refinery, and the water, which contains most of the recovered ammonia, is piped to the ammonia plant.

SCOTTISH SHALE-OIL REFINERIES.

In considering the following description of Scottish refinery practice, and referring to Figure 6, the reader should note that every distillation requires condensation, which in turn may require water. In addition, large quantities of steam are passed into the stills during

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practically all distillations. Every oil treatment uses sulphuric acid, frequently diluted with water, and caustic soda or soda ash in aqueous solution. In its travel from still to still, agitator to agitator, wax press to filter, the oil has to be forced by pumps or compressed air, and this, in its final analysis, requires more water. A reliable supply of reasonably good water is indispensable to the petroleum or shale-oil refinery.

In general, Scottish shale-oil refineries are similar to the American petroleum refineries, but differ considerably in detail. The Scottish refineries usually consist of the stills for fractionating the crude, and for re-running certain fractions; agitators and settling tanks, in which the oils are given acid and alkali treatments for the removal of some of the olefins, diolefins, nitrogen bases, and tarry products; paraffin and filter houses, where the heavy oil fractions are refrigerated and pressed for the separation of the wax; paraffin refinery for purifying and refining the wax; stock and storage tanks; shipping and packing departments, etc., and the candle house.

The following data regarding Scottish refining practice have been largely taken from an article, by Gavin:[7]

The crude oil, after having the bulk of the water separated, is run to the refinery. The refining of this oil is more involved and complicated than the refining of petroleum as the oil must be subjected to more acid and alkali treatments and a greater number of distillations. Therefore, a shale-oil refinery contains more small stills and agitators than does a petroleum refinery of equal capacity. More batch stills are used than continuous stills, and the Scottish shale-oil refineries have extraordinarily large wax plants compared with petroleum refineries of equal capacity.

Practically all refinery distillations are conducted with a large quantity of steam, which is admitted into the bottoms of the stills. The crude oil is run to coke as are also some of the redistilled oils.

The yield of refined products in Scotland is somewhat as follows:

Naphtha (including scrubber naphtha) 450° end point	9.9
Burning oils (kerosene and the like)	24.7
Gas and fuel oils	24.4
Lubricating oils	6.7
Wax	9.5
Still coke	2.0
Loss	22.8
	100.0

A general idea of the complexity of shale-oil refining in Scotland can be gained by referring to Figure 4, a generalized flow sheet of refinery operations at a typical Scottish shale works. This figure is presented through the courtesy of Scottish Oils (Ltd.). The writer wishes to express his appreciation particularly to H. R. J. Conacher of this organization for the use of these figures.

Scrubber naphtha, which the gasoline or naphtha recovered from the retort gases by washing them with oil and subsequently distilling the latter, amounts roughly to 2.4 gallons per ton of shale.

[7] Gavin, M. J., The necessity for research in the oil-shale industry: Chem. and Met. Eng., vol. 23, Sept. 8, 1920, pp. 489–495.

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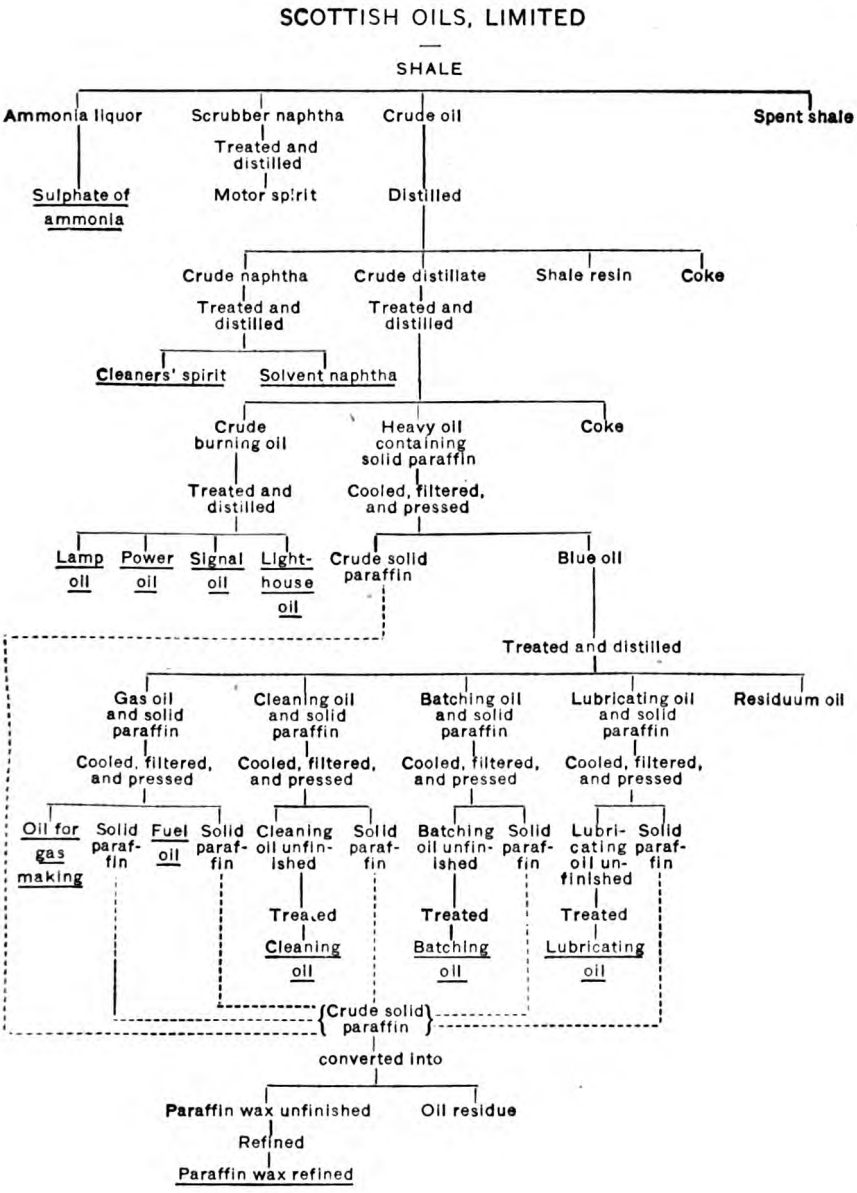

FIGURE 4.—Method of manufacture of mineral oils, paraffin wax, and sulphate of ammonia from oil shale (Scottish Oils, Ltd.).

AMMONIUM SULPHATE MANUFACTURE.

The success of the Scottish operators for so many years is largely due to the recovery of ammonium sulphate from the shale. Until 1865, however, it was not known that there was anything of value in the water obtained from the Scottish retort condensers. This water

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had been allowed to run to waste in fields, which became wonderfully productive.[8] Robert Bell, of Broxburn, Scotland, seeking the reason for the increased fertility, discovered that the water contained ammonia and in May, 1865, he began to market sulphate of ammonia made from this condenser water. Ammonium sulphate is highly valued as a fertilizer.

In present Scottish practice, where the retorts are steamed, about 60 per cent of the nitrogen in the raw shale is recovered as ammonium sulphate; more could be recovered, as will appear later (p. 20), but this yield seems to be the most economical. Many American shales are as rich in nitrogen as the Scottish shales, and in some places even richer. It is believed that ammonia compounds can be obtained from the American shales by methods practically the same as those used in Scotland, but whether ammonia recovery will be advisable or profitable remains to be seen.

In Scottish plants the condensed water from the retort condensers is separated from the oil, as has been noted above, and is then run to the ammonia plant. The gases that pass from the retort condensers are scrubbed with water to recover the balance of the ammonia and this scrubber water is also sent to the ammonia plant. Here the ammonia water is passed into the top of an ammonia tower or still, fitted with perforated baffle or bubbling plates, while steam under a moderate pressure is admitted to the bottom of the tower. About halfway down the tower, milk of lime is added to decompose fixed ammonia compounds and pyridine, which will not break up under the action of steam alone. The water flowing from the bottom of the tower passes through heat exchangers and thus heats the incoming water. The ammonia gas passes from the still into "cracker boxes" where it comes into contact with dilute sulphuric acid. The crystals of ammonium sulphate obtained are separated by different methods. The spent water from the tower is pumped over the spent-shale bing and wasted.

To produce ammonium sulphate requires large quantities of water, unless some of the more recently proposed "direct" processes are used. If the production of ammonium sulphate is contemplated, especial care should be taken to see that an adequate supply of water is available.

WATER REQUIREMENTS FOR AMERICAN OIL-SHALE PLANTS.

The water required in any or all of the operations of an oil-shale plant varies within wide limits, and depends largely on the type of equipment used, scale of operations, nature and number of products made, and the like. In turn these factors may depend, more or less, on the availability of water.

[8] Redwood, I. I., Mineral oils and their by-products. 1897, p. 169.

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Where the water supply is plentiful, no particular effort will have to be made to conserve it or to recover water for reuse. Where the primary supply is not adequate, every means will have to be used to conserve the water. In such places it may be expected that steam from the power plant will be condensed and reused, that attempts will be made to purify and reuse the water recovered in retorting, that oil condensation will be accomplished as far as possible by heat-exchanging devices, and that the water used for condensing will be cooled in towers or spraying ponds and repeatedly reused.

In certain localities it may be necessary to obtain the domestic water supply by distillation of water that is unfit, in the raw state, for domestic consumption, but perhaps entirely satisfactory for power and other purposes at the plant. At many places the water will have to be treated before it can be used in boilers, and at most places filtration will be required before the water may be used for either plant or domestic purposes.

MINING REQUIREMENTS.

As has been noted, the chief uses of water in mining operations will be for generating steam for power, and for domestic consumption by the miners and their families, who will make up a large proportion of the inhabitants of a shale-plant community.

LABOR REQUIRED FOR MINING OIL SHALE, BASED ON AMERICAN COAL-MINING PRACTICE.

In American coal mines the tonnage of coal mined per man varies considerably with the type of equipment used and the conditions of mining. Table 1 gives the average production, total number of men employed (including foremen, superintendent, shift bosses, etc.), days worked, and average tonnage per man, for stated periods up to 1913. Table 2 gives more complete data for the years 1914 to 1918, inclusive. From these tables it will be noticed that, as a rule and as would be expected, the tonnage mined per man increases with the use of machinery. For the purpose of making calculations of domestic water requirements for shale miners and their families, an average daily production of $3\frac{3}{4}$ to 4 tons per man will give a conservative figure. Probably in large shale mines this tonnage may be increased, as the tonnage mined per man will probably be greater than in coal mines, especially if the shale is mined for those plants and processes where a large percentage of fines will not prove objectionable. Then heavier powder charges may be used and more shale broken at each shot. Increased quantities of powder will also break the shale more and thereby decrease the amount of handwork necessary to break the larger pieces.

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TABLE 1.—*Coal-mining data, average production, number of men employed, days worked, and average tonnage per man, from 1886 to 1913.*[a]

State.	Period.	Production (short tons).	Number employed.	Days worked.	Average tonnage per man during period.
Colorado	1886–1913	6,008,413	8,693	230	3.00
Kentucky	1888–1913	7,144,744	12,361	201	2.88
Montana	1900–1913	2,115,567	2,921	239	3.03
Pennsylvania (anthracite)	1870–1913	50,316,598	117,851	200	2.14
Pennsylvania (bituminous)	1877–1913	69,596,423	89,076	229	3.41
Texas	1909–1913	2,061,793	4,720	236	1.85
Utah	1892–1913	1,440,197	1,744	254	3.25
Wyoming	1908–1913	6,820,359	7,716	232	3.81

[a] Fay, A. H., Coal mine fatalities in the United States 1870–1914, with statistics of coal production, labor and mining methods by States and calendar years: Bull. 115, Bureau of Mines, 1916, 370 pp.

The actual tonnage of oil shale mined per man per day will depend on many factors, the chief of which are: Character of the shale mined, equipment provided, thickness of seam or face, dip of strata, and method of mining.

It should also be noted that the average coal miner works only about 235 days a year. In calculating the water requirements of a community containing the men required to mine a certain daily tonnage of shale, it seems advisable—and this belief is checked by Scottish experience and statistics—to provide water for a larger labor force and families than will actually be required on a basis of $3\frac{3}{4}$ to 4 tons daily production per man.

WATER REQUIRED FOR POWER.

The water required for actual power purposes in the oil-shale industry will vary within wide limits. Ordinarily by far the largest amount of power required will be for mining. At many mines electrical power may be used, purchased from electric power companies, or possibly generated by generators driven by internal-combustion engines, using part of the fixed gases from the distillation of the shale. In many places where water is scarce it may be possible to use electric power generally for mining and other power requirements of the plant, thus decidedly decreasing the water required.

In estimating power requirements and the amount of water needed for steam generation, provision should be made for generating electricity for mine lighting, if the electricity is to be steam generated. It is possible that some shale mines will make water, but such are likely to be exceptional. Where water is encountered in shale mines, power may be needed to pump it out. Most of the power will be required for mining operations, ventilation, and hoisting.

Provision should be made for power for crushing, the amount of which will depend on the nature of the shale, degree of fineness required, and scale of operations.

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TABLE 2.—*Coal-mining data for Colorado, Kentucky, Montana, Pennsylvania, Texas, Utah, and Wyoming, 1914–1918 inclusive.*

State and year.	Production (short tons).	Number employed.	Days worked.	Average tonnage per man.		Percentage of coal mined by—				Number and kind of machines.					
				Per year.	Per day.	Hand.	Machine.	Shot off solid.	Not reported.	Pick.	Chain breast.	Long-wall.	Short-wall.	Radial ax or post.	Total.
Colorado:															
1914	8,170,559	10,098	244	809	3.32	57.3	30.6	11.6	0.5	168	35	11	87	5	306
1915	8,624,980	12,372	194	697	3.60	57.8	30.5	11.3	.4	.....	.....	.....	.....	.....	299
1916	10,484,232	13,104	233	800	3.43	51.4	31.9	16.1	.6	.....	.....	.....	.....	.....	305
1917	12,483,336	14,231	263	877	3.33	.....	.....	.....	.....	.....	.....	.....	.....	.....	328
1918	12,407,571	14,483	255	857	3.36	54.0	36.9	7.3	1.8	.....	.....	.....	.....	.....	352
Kentucky:															
1914	20,382,763	28,764	187	709	3.79	9.8	77.2	11.6	1.4	590	369	40	367	17	1,383
1915	21,361,674	27,960	186	764	4.11	6.8	81.8	10.6	.8	.....	.....	.....	.....	.....	1,399
1916	25,393,997	31,222	208	813	3.91	6.0	84.4	9.0	.6	.....	.....	.....	.....	.....	1,528
1917	27,807,971	34,926	214	796	3.72	.....	.....	.....	.....	.....	.....	.....	.....	.....	1,514
1918	31,612,617	39,342	230	804	3.50	4.3	78.5	15.1	2.1	.....	.....	.....	.....	.....	1,634
Montana:															
1914	2,805,173	3,350	209	837	4.00	24.2	43.3	31.9	.6	57	21	.....	20	1	99
1915	2,789,755	3,158	201	883	4.39	23.0	55.0	21.0	1.0	.....	.....	.....	.....	.....	100
1916	3,632,527	3,781	244	961	3.93	34.1	55.7	9.5	.7	.....	.....	.....	.....	.....	103
1917	4,226,689	4,149	268	1,019	3.80	.....	.....	.....	.....	.....	.....	.....	.....	.....	115
1918	4,532,505	4,559	264	994	3.77	21.2	50.0	28.2	.6	.....	.....	.....	.....	.....	116
Pennsylvania (bituminous):															
1914	147,983,294	184,201	214	803	3.75	37.2	53.8	2.0	7.0	3,140	1,927	96	1,156	7	6,326
1915	157,955,137	174,593	226	905	4.00	34.5	55.6	9.7	.2	.....	.....	.....	.....	.....	5,935
1916	170,295,424	168,212	259	1,012	3.91	35.0	55.4	9.3	.3	.....	.....	.....	.....	.....	5,768
1917	172,448,142	173,968	261	991	3.80	.....	.....	.....	.....	.....	.....	.....	.....	.....	6,004
1918	178,550,741	174,306	269	1,024	3.81	35.7	55.0	6.9	2.4	.....	.....	.....	.....	.....	6,207
Texas:															
1914	2,323,773	4,635	237	501	2.11	72.5	1.2	26.3	.....	9	.....	2	2	.....	13
1915	2,088,908	5,087	233	411	1.76	76.4	1.6	22.0	.....	.....	.....	.....	.....	.....	10
1916	1,987,503	4,481	218	444	2.04	78.0	1.0	21.0	.....	.....	.....	.....	.....	.....	10
1917	2,355,815	4,375	263	538	2.05	.....	.....	.....	.....	.....	.....	.....	.....	.....	1
1918	2,261,135	3,936	262	574	2.19	76.0	.1	21.5	2.4	.....	.....	.....	.....	.....	1
Utah:															
1914	3,103,036	4,112	210	755	3.60	63.6	30.4	5.9	.1	.....	9	.....	59	.....	68
1915	3,108,715	3,564	208	872	4.19	47.3	49.6	2.9	.2	.....	.....	.....	.....	.....	67
1916	3,567,428	3,129	228	1,140	5.00	41.7	57.5	.8	.....	.....	.....	.....	.....	.....	78
1917	4,125,230	3,483	219	1,184	5.41	.....	.....	.....	.....	.....	.....	.....	.....	.....	105
1918	5,136,825	4,160	258	1,235	4.79	36.7	53.9	9.2	.2	.....	.....	.....	.....	.....	141
Wyoming:															
1914	6,475,293	8,117	192	798	4.16	23.7	42.2	34.0	.1	56	78	2	48	14	198
1915	6,554,028	7,244	201	905	4.50	21.9	44.6	33.4	.1	.....	.....	.....	.....	.....	179
1916	7,910,647	7,255	248	1,090	4.40	22.8	44.0	33.1	.1	.....	.....	.....	.....	.....	192
1917	8,575,619	7,358	246	1,165	4.74	.....	.....	.....	.....	.....	.....	.....	.....	.....	161
1918	9,438,688	7,554	268	1,249	4.66	21.6	47.3	29.7	1.4	.....	.....	.....	.....	.....	163

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It has been noted that in many places it may be advisable to install condensing systems in connection with the power plants, and thereby conserve the water used for power. To do this may be cheaper than to develop additional water supplies.

While it is impossible to make reliable general estimates of power requirements for shale mining, it is believed that the following information on coal mining may at least form a basis for preliminary estimates.

POWER INSTALLATIONS AT TYPICAL EASTERN COAL MINES.

Data on power installations at different coal mines in the eastern fields of the United States are taken from unpublished coal-mining reports of the Bureau of Mines.[9] The capacity of the power equipment installed in different mines varies considerably, but in the compilation of this table an effort has been made to list mines operating under average conditions and using methods similar to those that will have to be employed where the shale is mined selectively and only the richer shale beds or strata are removed. The methods of mining will probably be similar to those of coal mining—long-wall or room-and-pillar, with main and butt entries and panels.

An average of the mines listed in Table 3 gives an installation of approximately 0.455 kw. per ton of coal capacity of the mine. This figure includes the power required for pumping mine water, which in some mines requires more power than the actual mining and haulage. Many of the shale mines will be above the streams draining the region and much of the mine water may be removed by gravity, as in many drift coal mines. Attention is called to the fact that as yet the possibility of successfully mining oil shale by mining machines has not been demonstrated. Practically all oil shale is very tough and tenacious. Very few machines are used in Scotland and nearly all of the shale is mined by first breaking with powder.

The average of 0.455 kw. per ton of coal mined does not include the power that would be required at oil-shale plants for crushing the shale or the power required for pumping enough water to supply the retorts. On the basis of coal-mining practice and under average conditions, the water required for power purposes will vary from as low as 2.5 to as much as 6 gallons per hour for each kilowatt of electric current required in the mining operations.

DATA ON POWER PLANTS AT TYPICAL UTAH COAL MINES.

The following somewhat incomplete data from typical coal mines in Utah have been supplied through the courtesy of Mr. R. S. Lewis, professor of mining engineering, University of Utah.

[9] Courtesy of the mining division, U. S. Bureau of Mines.

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SPRING CANYON COAL CO.

Capacity: 1,800 tons of coal a day.

Water: 162,000 gallons a day total; 154,000 gallons a day for domestic purposes 8,000 gallons a day for box-car loader.

Population served: 700.

Horsepower for town lighting: 50.

Total horsepower (in mine) purchased from electric power company: 1,350 maximum to 150 minimum.

CASTLE GATE MINE.

Capacity: 2,439 tons a day from two mines.

Power installations: Eleven 125-horsepower boilers and two Curtis turbines, each 500 kw., at 2,300 to 4,000 volts, using steam at 150 pounds pressure.

Population served: About 1,500.

CANERON MINE.

Capacity: 850 tons a day.

Water: 25,000 gallons a day for domestic purposes.

Power purchased: 2,500 kw.-hours average used, 90 per cent for mining operations and 10 per cent for lighting.

Population served: 500 residents (170 employees).

SUNNYSIDE MINE.

Capacity: 2,450 tons a day.

Power installation: (1) 16 fire-tube boilers of 125 horsepower each for full power demand, with two other boilers in reserve; (2) 2 d. c. generators, 436 amperes, 525 volts; (3) 1 three-phase a. c. turbogenerator, 375 kva. at 3,400 volts, using steam at 60 pounds pressure; (4) 1 Curtis turbine, 500-kw. generator at 2,200 to 4,000 volts.

Population served: About 2,500.

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TABLE 3.—*Coal-mining data.*

Mine No.	Number of beds worked.	Thickness.	Kind of coal.	Capacity per day, tons.	Actual average per day, tons.	Number of men working— Underground.	Number of men working— Above ground.	Total number of men working.	Average tonnage mined per man per day.	Total electric power installation, kw.	Kw. provided per ton of coal mined at maximum capacity.	Coal-cutting machine (make and type.)	Number used.	Haulage system.	Number of locomotives.	System of mining.	Steam equipment. Boilers, number.	Steam equipment. Horsepower, total.
1	1	5 feet 6 inches...	Bituminous.....	750	600	85	19	104	5.77	200	0.266	Jeffrey and Sullivan.....	6	Electric.....	5	Room and pillar.	....	....
2	1	4 feet 4 inches...	.....do.....	400	300	48	11	59	5.07	300	.750	Jeffrey.....	3	.....do.....	4	Panel.....	4	600
3	1	4 feet 6 inches...	New River smokeless.	1,800	1,600	250	100	350	4.57	.....	.....	6 Goodman short-wall; 4 Sullivan; 3 Morgan-Gardner turrett.	13	.....do.....	17	Room and pillar.	....	....
4	1	5 feet 6 inches...	Bituminous.....	.....	400	72	6	78	5.07	240	.....	Morgan-Gardner short-wall..	2	.....do.....	6	Panel.....	....	....
5	1	4 feet 9 inches...	.....do.....	350	300	65	20	85	3.53	200	.572	Goodman short-wall; Morgan-Gardner; Sullivan.	3	Electric and mules.	3	Room and pillar, long wall.	....	....
6	1	5 feet to 5 feet 6 inches.	.....do.....	.....	.....	.....	.....	.....	.....	200	.....	Jeffrey short-wall.....	1	Electric.....	[a] 2	.....	....	....
7	1	5 feet 6 inches...	.....do.....	250	200	25	5	30	6.67	(b)	.....	Morgan-Gardner.....	2	Mule.....	....	Room and pillar.	....	....
8	1	7 feet.....	Semibituminous..	600	500	60	20	80	6.25	150	.25	Sullivan, C. E., short-wall...	5	Mules and motors.	4	Panel.....	....	....
9	1	30 inches.....	.....	.....	50	10	3	13	3.85	[c] 150	.....	Goodman 12 A. A.....	1	Electric.....	1	Room and pillar.	....	....
10	1	4 feet.....	Semibituminous..	.....	100	11	3	14	7.15	.....	.....	.....	....	4 mules.....	....	Drawing pillars.	....	....
11	1	4 feet 2 inches....	.....do.....	800	.....	60	25	85	.....	[d] 200	.400	No. 35 B. Jeffrey short-wall..	3	Electric.....	8	Room and pillar and panel.	....	....
12	1	4 feet to 10 feet..	.....	1,800	1,600	180	120	300	5.33	450	.281	4 Goodman; 1 Sullivan.....	5	.....do.....	11	Room and pillar.	....	....
13	1	.....	.....	1,200	950	125	75	200	4.75	.....	.....	Goodman short-wall.....	5	.....do.....	10	.....do.....	....	....
14	2	6 feet and 4 feet .	High volatile.....	1,500	800	200	20	220	3.63	[c] 200	.133	6 Jeffrey short-wall; 3 Jeffrey arc-wall.	9	.....do.....	18	.....do.....	2	100
15	2	5 feet each.....	High volatile bituminous.	.....	750	163	10	173	4.34	400	.....	Jeffrey No. 35 B short-wall..	7	.....do.....	7	Panel.....	....	....
16	1	6 feet 6 inches...	Semibituminous..	450	.....	65	10	75	.....	150	.333	Sullivan short-wall.....	2	Electric and mule.	3	Room and pillar.	....	....
17	1	3 feet to 6 feet...	Bituminous.....	.....	250	35	20	55	4.54	200	.....	Jeffrey arc-wall.....	2	Electric.....	5	Room and pillar and panel.	....	....

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18	1	Average 4½ feet	New River smokeless.	1,000	855	190	85	275	3.11	675	.675	1 Jeffrey; 6 Goodman; 6 Sullivan.	13	....do	24	Room and pillar.	3	900
19	1	....do	....do	300	280	50	30	80	3.5	165	.55	Goodman short-wall; Goodman slabbing.	2	....do	4	....do	2	300
20	1	4 feet 2 inches	Smokeless	800	650	90	40	130	5.0	400	.50	Jeffrey No. 35 B short-wall	4	....do	9	....do	....	....
21	1	6 feet	Bituminous	....	500	70	13	83	6.02	200	....	Goodman 12 A. B. short-wall	2	....do	6	Panel	....	....
22	1	4 feet 2 inches	....do	200	150	22	10	32	4.68	150	.75	Goodman short-wall	1	Electric and mule.	1	Room and pillar.	1	150

a 6-ton. b Purchase direct current. c Motor generator. d Converter.

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RETORTING OPERATIONS.

The amount of water used in the oil-shale retorting process will depend on the type of process used, richness of the shale, scale of operations, and method of condensing shale-oil vapor.

EFFECT OF TYPE OF PROCESS.

As has been mentioned many of the shale processes proposed for use in the United States involve the production of oil without the use of steam in the retort. If this method can be used, and a satisfactory oil produced, the water requirements for retorting will be relatively negligible, amounting practically to that used in generating steam or power for conveying raw and spent shale, transfer pumps, moving, agitating, and discharge mechanisms and other similar equipment. The use of steam in the retort may be desirable, both for increasing yield of oil and for producing greater ammonia yields.

The Scottish type of retort requires for steam about four gallons of water per gallon of oil produced. That is to say, if a retorting plant produces 1,000 barrels of oil per day, 4,000 barrels or 168,000 gallons of water will be put into the retorts as steam. Obviously a retort that requires steaming will require more water, and it is questionable if much satisfaction will attend attempts to recover such water for reuse after the ammonia has been abstracted. It is very necessary that the desirability of steaming retorts and the conditions under which steam may best be used be determined as soon as possible, since these data will have a decided bearing on the problem of water supply.

EFFECT OF RICHNESS OF SHALE.

It will be noted that the amount of steam used in the Scottish retort is based on the amount of oil produced rather than on the weight of shale put through. In other words, it is not strictly correct to state that a certain amount of water is used per ton of shale retorted, but estimates should be based primarily on the amount of oil to be produced in a given period. A shale yielding 60 gallons of oil per ton will apparently require, according to the Scottish practice, twice as much steam per ton as one yielding only 30 gallons per ton.

PRODUCTION OF AMMONIUM SULPHATE.

The writer has no separate data regarding the amount of water used in the production of ammonium sulphate in the Scottish shale plants, as the water used in this stage belongs to the retorting requirement. From a reference to the description of the method used in the production of ammonium sulphate, it will be noted that, aside from steam for power purposes, large amounts of water are required for scrubbing the gas, and live steam is required for the ammonia

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stills. It seems likely that the greater part of the water used in the ammonia scrubbers may be recovered, cooled, and used for scrubbing several times. When the concentration of certain impurities exceeds a certain point, it may be necessary to change the water, though it is possible that by proper methods it might be made fit for further scrubbing, or possibly boiler or condenser use.

In the production of ammonium salts, water may be required to dilute the fixing acid, usually sulphuric acid, as has been noted.

WATER REQUIREMENTS IN SCOTTISH RETORTING PLANTS.

The following data regarding Scottish practice,[10] although strictly applicable only to operations as carried out in Scotland and to the particular type of shale retorted there, may be of possible service as forming at least a tentative basis on which to estimate water requirements of American shale retorting plants. It is to be noted that steam is used in the Scottish retorts, that no water-cooled crude-oil condensers are used, and that the figures given below include water required for scrubbing the gases for ammonia and the manufacture of ammonium sulphate.

A Scottish retorting plant capable of retorting daily 500 long tons (2,240 pounds to the ton) or 560 short tons of shale, yielding 20 imperial gallons of oil and about 40 pounds of ammonium sulphate per long ton, requires about 75,000 imperial gallons of water per day, of which none is recovered.

When these figures are converted to United States measurements, they read as follows:

Throughput of shale	tons..	560
Oil recovered	gallons..	12,000
Ammonium sulphate produced	pounds..	20,000
Water required	gallons..	90,000

Inasmuch as it is believed correct to rate the capacities of shale plants on the basis of oil made rather than of shale mined, the water requirements per gallon of oil produced, based on Scottish practice, is therefore $\frac{90,000}{12,000}$ or 7.5 gallons. This of course includes the manufacture of the equivalent of about 1.66 pounds of ammonium sulphate per gallon of oil; if the ratio of ammonia to oil is greater or less than this, the estimated water requirements must be altered accordingly. In Scotland the steam for the retort is usually exhaust steam from the power plant.

REUSE OF WATER FROM THE RETORT.

The short time of contact between the hot shale and the water vapor in the retort suffices to decompose only a small percentage of the water used in the retorting process. Consequently, much of the steam will be condensed and collected with the hydrocarbon and other vapors evolved during retorting.

[10] Scottish Oils (Ltd.), Glasgow, Scotland, personal communication to M. J. Gavin.

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It seems probable, however, that the use of this recovered water which contains large amounts of sulphur, nitrogenous, and other compounds, may have a detrimental effect on the oil produced. In the Scottish plants the waste waters from the retorting process are not usually reused but are allowed to trickle over the spent-shale dumps and then waste.

The possibility of purifying the water recovered in retorting to make it suitable for further use either in the retort or elsewhere in the plant is taken up later. (See pp. 35 to 37.)

CONDENSATION OF VAPORS FROM RETORTS.

In Scotland, as already noted, water is not required for the retort condensers. At the Scottish plants the oil and water vapors leave the retorts by a vapor line, usually about 6 to 8 inches in diameter, and enter a main vapor line of about 30 inches in diameter. In some plants the vapors go first to a form of feed-water heater where they impart some of their heat to the water for the steam boilers, etc. From the preheater the vapors pass into the vertical air condensers arranged in the form of a series of inverted U's. These U condensers are formed of thin-walled cast-iron pipe, usually about 4 inches in diameter, mounted vertically on headers from which slightly different fractions might be recovered through partial fractionation in the condenser. No effort is made to take advantage of any such fractionation, however, as the oil from all the headers is combined before going to the refinery. The vapors enter the largest header, pass upward through one leg of the multiple inverted U condensers and down the other side into a second header, from which they again pass upward through a second set of similar inverted U condensers. The heaviest fractions, with the highest condensation temperatures, condense first and collect in the first headers. The lighter hydrocarbon fractions with the water vapors are condensed in the last sections of the condenser and collected in the last headers. This procedure is advantageous because the heavy fractions are mostly condensed before the vapors reach a temperature of about 212° F., the condensation point for water. As a result, the formation of troublesome emulsions between many of the heavier hydrocarbon fractions and the water is prevented.

The comparatively low atmospheric temperatures and uniform climatic conditions existing in the shale areas of Scotland allow air condensers to operate with a fair efficiency the year round. In a majority of the shale regions of America, however, the great variations in temperature (see Figs. 5 and 6) will impair the functioning of air condensers and render them subject to clogging during the colder months of the year by the congealing of the heavier fractions in the condenser. An example of the great temperature variations

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in the mountainous shale regions may be seen in the curves of Figures 5 and 6, which show graphically the average monthly temperatures for, respectively, Rifle and Grand Valley, Colo.[11] The lowest temperature recorded in the 22-year record for the Grand Valley is –25° F. in January; the highest was 104° F. in July and August. The annual

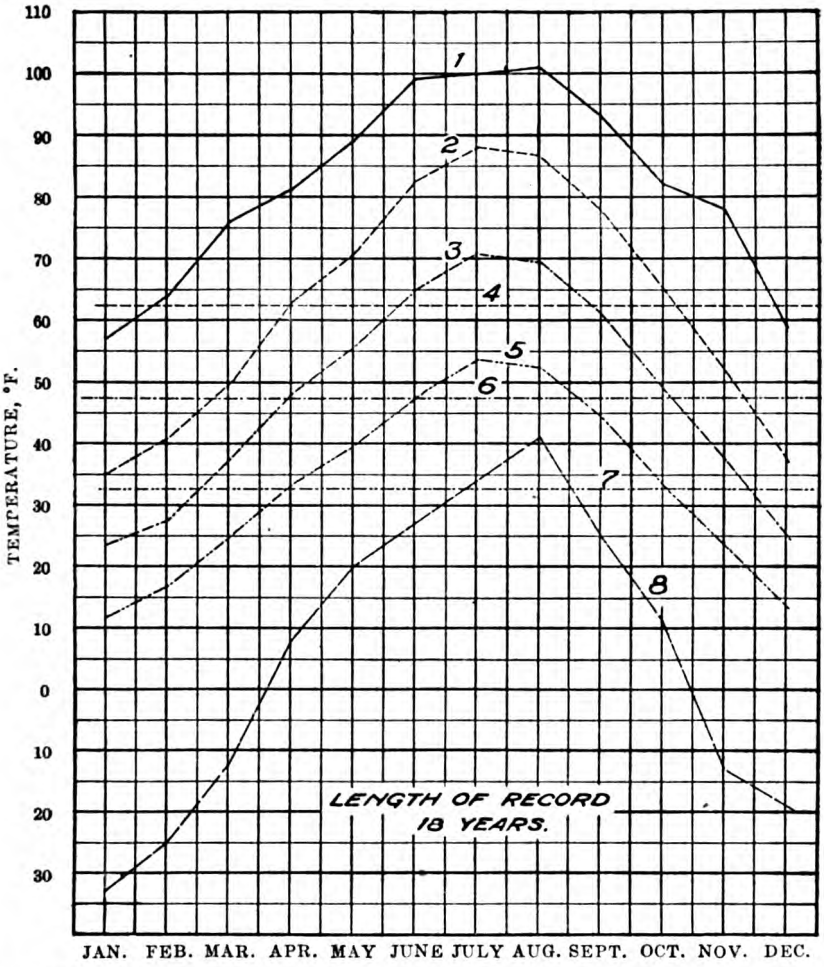

FIGURE 5.—Curves showing temperatures for Rifle, Colo.: 1, Highest temperature; 2, mean maximum temperature; 3, mean temperature; 4, annual mean maximum temperature; 5, mean minimum temperature; 6, annual mean temperature; 7, annual mean minimum temperature; 8; lowest temperature.

mean minimum temperature during this 22-year period was about 32° F., and the annual mean maximum temperature about 65° F.

Owing to the consequent difficulty of making effective use of air-cooled condensers, it seems advisable in preliminary estimates of water requirements for shale plants to allow for water-cooled con-

[11] Sherier, J. M., Climatological data for the United States—Colorado section; regions drained by the Colorado and Rio Grande Rivers in Colorado, vol. 9, 1922; vol. 10, 1923.

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densers for the condensation of the vapors from the retorts, or at least to plan replacing part of the air-cooled with water-cooled condensers. The calculation of condenser surface for vapors is discussed in textbooks and many recently published articles, and space need not be devoted to it here.[12]

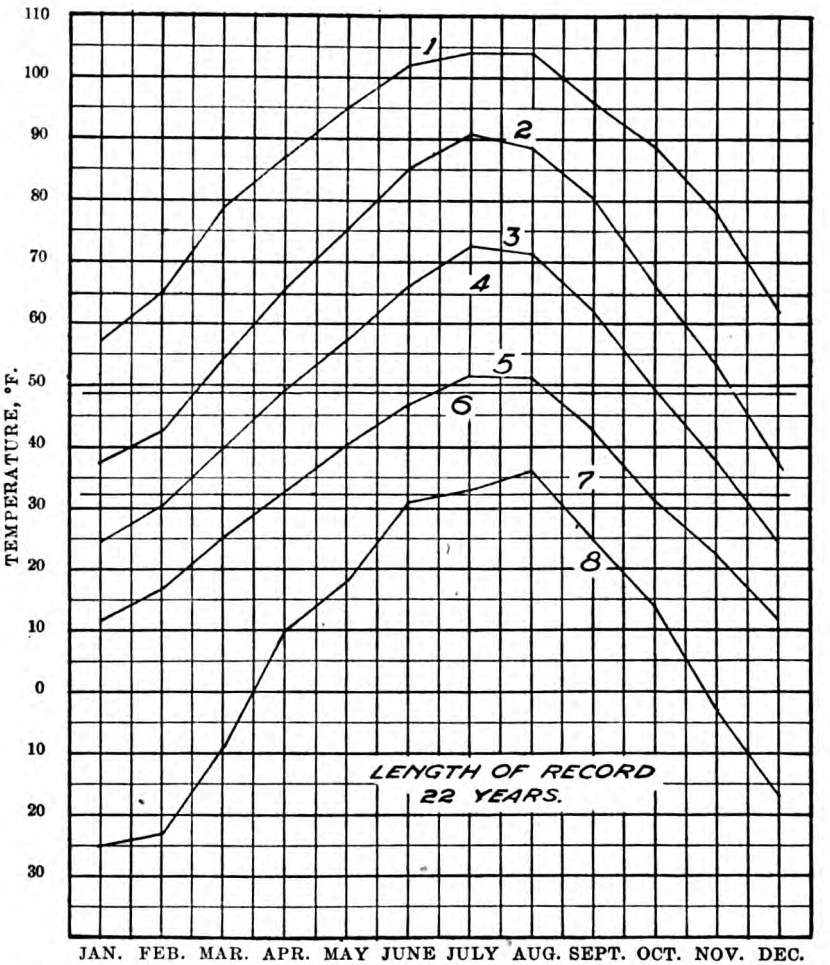

FIGURE 6.—Curves showing temperatures for Grand Valley, Colo.: 1, Highest temperature; 2, mean maximum temperature; 3, mean temperature; 4, annual mean maximum temperature; 5, mean minimum temperature; 6, annual mean temperature; 7, annual mean minimum temperature; 8, lowest temperature.

[12] For additional information on condensers, water requirements, etc., the reader is referred to the following publications:

Hausbrand, E., Evaporators, condensing and cooling apparatus, experimental formulas and tables for use in practice. Translated from the second German edition by A. C. Wright, 1903, 400 pp.

Richter, G. A., Double-pipe heat interchangers: Met. and Chem. Eng., Mar. 24, 1920, pp. 551–556.

Bacon, R. F. and Hamor, W. A., The American petroleum industry. 1916, pp. 735–744.

Wadsworth, J. M., Removal of the lighter hydrocarbons from petroleum by continuous distillation: Bull. 162, Bureau of Mines, 1920, 162 pp.

Redwood, I. I., A practical treatise on mineral oils and their by-products. 1914, p. 202; see also page 108 for the latent heats of evaporation of petroleum and its products, and page 104 for specific heats.

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WATER CONSUMPTION OF SCOTTISH REFINERIES.

The following data, obtained through the courtesy of Scottish Oils (Ltd.), Glasgow, Scotland, are for present-day practice in Scottish shale-oil refineries, and are representative of refineries producing a complete line of products, including paraffin wax, three grades of light lubricating oils, five or six grades of illuminating and power oils, and two to four grades of motor fuels and naphthas.

A refinery with a daily capacity of about 10,000 imperial gallons of crude shale oil requires each day about 25,000 imperial gallons of water, of which about one-fifth is recoverable; thus the net consumption daily is 20,000 imperial gallons, or 2 gallons of water for each gallon of crude shale oil refined. Undoubtedly most of this water is used in the chemical treatments, as the water for condensers may readily be cooled and reused and only a relatively small amount is needed to replace that lost by evaporation.

In localities where water is scarce many shale plants may possibly so treat the water produced in retorting that it can be used for condensing. Care would have to be taken that the water contained nothing that would attack the metal of the condensers. A general application of heat-exchanging devices to the condensing system will also decrease the condenser water required.

WATER REQUIREMENTS FOR REFINING.

The amount of water used in shale-oil refining will depend largely on the following factors: Scale of operations, type of equipment used, nature of crude oil, and nature and number of finished products made.

Water will be required for cooling and condensing vapors from crude and rerun stills and for supplying steam to most of these stills during distillation. Scottish operators find it necessary to rerun their shale-oil distillates many more times than is necessary for distillates of average petroleum. Moreover, more distillations are made with steam than, commonly, in refining petroleum. Another point that deserves emphasis is that in refining shale oil there are more chemical treatments, with more dilute reagents, than are customarily used with petroleum. Consequently, much more water will be required than in similar operations for average petroleum. The recovery of wax also, usually present in greater quantities in shale oil than in petroleum, will require large amounts of water.

The crude oils recovered from different American shales will differ materially in composition, as also oils made from a given shale by different processes. Consequently, the methods of refining and the amounts of water required will differ.

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WATER CONSUMPTION OF AMERICAN PETROLEUM REFINERIES.

The following data on water requirements of petroleum refineries give an idea of the amount of water consumed by different types of refining plants. As noted, it is likely that a shale-oil refinery will consume more water than a petroleum refinery of equal capacity yielding products of the same general nature.

EMPIRE REFINERY AT OKMULGEE, OKLA.[13]

This is a complete refinery, manufacturing distillate, lubricating oils, wax and cylinder stocks, in addition to the regular light oils. It has a refinery capacity of 1,750 barrels of crude oil daily, with the following estimated amount of water circulated daily:

	Gallons.
Stills	2,500,000
Wax plant	600,000
Agitators	9,000
Boilers	85,000
Total	3,194,000

An average of about 280,000 gallons of water per day is purchased as make-up water. The number of gallons of water circulated per gallon of crude oil treated is estimated in the following manner:

$$\frac{3,194,000}{1,750\times 42}=43.4 \text{ gallons.}$$

The number of gallons of make-up water required per gallon of crude treated is figured as follows:

$$\frac{280,000}{1,750\times 42}=3.81 \text{ gallons.}$$

EMPIRE REFINERY AT CUSHING, OKLA.[14]

This plant is a typical skimming plant of the Mid-Continent district and manufactures gasoline, naphtha, kerosene, gas oil, and markets the residuum as fuel oil. Kansas crude is treated, of which approximately the following yields are obtained:

	Per cent.
Gasoline and naphtha	30
Kerosene	10
Gas oil	8
Fuel oil	50
Loss	2
	100

[13] Wadsworth, J. M., general superintendent, Empire Refineries (Inc.), personal communication.
[14] Wadsworth, J. M., cited.

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The daily skimming capacity is 4,000 barrels of crude. Following is the estimated quantity of water circulated daily:

	Gallons.
Stills	4,000,000
Boilers	56,000
Agitators	14,000
Total	4,070,000

The number of gallons of water circulated per gallon of crude oil treated is approximated by the following figures:

$$\frac{4,070,000}{42 \times 4,000} = 24.2 \text{ gallons.}$$

CALIFORNIA TOPPING PLANTS.

Investigations [15] regarding water requirements of different types of topping plants in California reveal the following facts:

AVON PLANT.

Type: Two batteries of conventional stills, capacity 13,000 barrels daily of 26.0° B. crude, and two topping stills of A. F. L. Bell type, handle about 7,000 barrels of the same crude per still per day. The total daily capacity is 20,000 barrels under normal conditions, from which is made about 122,500 barrels of tops a month. The tops yielded about 37 per cent gasoline, 26.5 per cent engine distillate, 12.5 per cent stove oil, and 24 per cent steam still bottoms. Steam charged to conventional and topping stills totaled 350 boiler horsepower daily. Cooling and condensing water was pumped from the bay, and in topping plants the amount required was low because of highly efficient heat exchangers. Conventional stills required about 14 barrels of water for 1 barrel of tops for condensing, and toppers 3.5 barrels per barrel of crude oil.

I. W. FUQUA TOPPING PLANT AT FELLOWS, CALIF.

This plant is intended to top and dehydrate rather wet oil. On dry oil it removes from 20,000 barrels of crude daily, a 15 per cent cut at 350 to 400° F. The amount of water in the oil decreases this capacity in proportion to the percentage of water. Ordinary steam requirements were 150 boiler horsepower daily. Condenser water was cooled in towers and reused, the amount required to make up for evaporation being obtained by the dehydration of the crude. About 800 barrels of this make-up water were required.

[15] Wadsworth, J. M., Removal of lighter hydrocarbons from petroleum by continuous distillation: Bull. 162, Bureau of Mines, 1919, pp. 4, 16, 29, 47, 48, 60.

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SUMMARY OF WATER REQUIREMENTS FOR A SCOTTISH OIL-SHALE RETORTING AND SHALE-OIL REFINING PLANT.

When the Scottish method is used, a retorting plant capable of producing 1,000 barrels of crude oil and 39,720 pounds of ammonium sulphate per 24-hour day would require a daily supply of 315,000 gallons of water. A refinery capable of treating the same quantity of products would require 84,000 gallons of water a day. These figures indicate that one-fifth of the water used in refining can be recovered.

WATER FOR DOMESTIC USE.

The per capita water requirement for mining, for construction, and for operating plants varies considerably with the climatical conditions, type of work, and classes of laborers employed. This factor is discussed at greater length in the section on sanitation in oil-shale camps, pages 52 to 53, but may be summarized here.

The per capita domestic water requirements for different mining camps vary from as low as 6 gallons daily (the minimum necessary for existence) to as high as 150 or more gallons daily. At the Scottish shale works the domestic requirements are 100 gallons a person, and the total population is about one person for each ton of shale put through the plant a day.[16]

One of the greatest assets to a mining community is a plentiful supply of good water. Calculations for water requirements for domestic use, whenever at all possible, should be based upon a daily per capita supply of not less than 30 gallons.

SOURCES OF WATER SUPPLY FOR THE OIL-SHALE INDUSTRY.

As this paper is written largely from the point of view of an operator in the oil-shale region of the Rocky Mountain district, the data gathered from this section may not be applicable to operations in other parts of the United States where water supplies are generally more adequate. No operations should be started unless there is certainty that a reliable and adequate supply of water for both plant and domestic use is or can be available; in view of this fact much of the following material will be of use to oil-shale operators throughout the country.

In the Eastern States generally water resources are fairly well known. In the West, however, and particularly where the oil-shale deposits occur, we have accurate determination of only the larger streams and their main tributaries. The operator will be able to secure reliable data as to water supplies from the United States Geological Survey, from the various State engineers, or other State

[16] Scottish Oils (Ltd.), Glasgow, Scotland, personal communication to M. J. Gavin.

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officials concerned with water rights, supplies, and resources. Frequently, however, the operator will find data inaccurate or utterly lacking, especially for many of the smaller streams that may be considered important in supplying water for a shale plant. The following suggestions are offered for the benefit of those who are unable to obtain reliable information, and at the end of this paper there is a brief list of references to textbooks and articles in periodicals dealing with stream flow and water development.

CALCULATIONS FOR STREAM FLOW.

In the operation of large shale plants, the average total 24-hour daily demand for water will probably not vary greatly during the year. However, in studying the available supply and the effect on the stream flow of the demand for water in operating the plant, it will be necessary to take into account water previously decreed for irrigation and other purposes. The total amount of water drawn from the stream will not be uniform throughout the year in such cases. The demand for irrigation will vary considerably from season to season, being greatest during the growing period, while through the remainder of the year the water will often have to be stored if the entire flow of the stream is to be conserved. On streams where a limited supply of water is available and only sufficient to meet the present demands and decrees, future legal adjustments will have to be made if there is to be a considerable development of the shale industry. Under existing laws the industrial communities of the shale regions will have first or prior rights to the limited water supply, irrigation second, and last the shale plant. A few laws and regulations governing the proportioning of water are given in a brief outline of regulations governing decrees of and the pollution of waters (pp. 45 to 49).

RIVER WATER SUPPLIES AND EFFECTS OF SEWAGE.

The problem of disposition of sewage and refuse from the communities surrounding the shale plants requires attention. Should the oil-shale industry assume its predicted rôle of supplementing materially our crude oil supply, the shale districts will require a large labor force which may be augmented to equal or outnumber the industrial force of our present coal-mining organization. This army of laborers will probably be concentrated in small units and the different communities may be too close together to allow sewage time for natural purification if the refuse be discharged into a stream without treatment. In some shale districts, it may eventually become necessary to require the use of septic tanks and prohibit the direct pouring of sewage into the common streams.

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PONDAGE AND STORAGE CALCULATIONS.

An engineer calculating the water requirements for shale plants will often do well to consider the variations in load between night and day, even on those streams where large pondage and storage is not practicable. On many of the streams storage will not be possible, and consequently, if the water is not to be wasted it will have to be utilized as it flows. The hourly demand for water in the shale plant will vary, even though the retorts operate continuously 24 hours a day. During the day, because of auxiliary operations and domestic consumption, the demand will be greater than at night. If the plant is situated on a small stream where the flow during certain seasons of the year is not quite enough to meet the peak demand for water, this demand may possibly be met by utilizing pondage. A part of the otherwise unutilized flow of the stream can be impounded during periods of light load and held till needed, thereby increasing the daily output of the stream over such short periods. Thus if the water is used only 12 hours daily, and the total night flow can be impounded and utilized during the day, the available supply of water for day use will be doubled. As pondage and storage interfere with the normal flow of the stream, the effect of the interference on other plants should receive careful consideration. On streams from which water is to be drawn for many plants it may be advisable to study the effect of pondage on stream flow. A number of good storage sites are available in many oil-shale localities, but on most of the streams development of adequate storage facilities will be costly. In practically all of the extensive oil-shale regions in this country, cooperation between the State, the users of irrigation water, and the oil-shale companies should permit the development of a supply of water sufficient to take care of a large shale industry and its communities.

WATER IN STORAGE RESERVOIRS.

Water drawn from large storage reservoirs is seldom detrimental to the health of consumers. Storage greatly minimizes the danger from any pathogenic pollution to which the water may be subjected before it reaches the reservoir, and thus substantially improves the physical quality of the water.

Practically all waters, however, become stagnant when stored for long periods in lakes or impounding reservoirs. The stagnation does not ordinarily occur throughout the body of the water, but is largely confined to the lower or bottom layers, where, largely through the action of bacteria upon the deposits of organic matter, the oxygen in the water is entirely consumed, with the consequent production of foul tastes and odors. Many attempts have been made to overcome this undesirable feature in stored water, one of the best methods being aeration and filtration. Usually, the odors and

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tastes due to stagnation are not as troublesome as those due to certain forms of animal and vegetable life, commonly known as algæ. The offensive results are caused by the essential oils which these organisms secrete during their growth in the warm months.

The development of algæ can be prevented by treatment with copper sulphate ($CuSO_4$), about 1 part in 3,500,000 to 1,000,000 parts of water. In small reservoirs the growths may be prevented by the construction of a light-tight roof.

ESTIMATING DISCHARGE FOR PRELIMINARY PLANT LAYOUT.

Discharge records of many of the smaller streams tributary to some of the sparsely settled and undeveloped shale regions have not been made. For preliminary data, however, engineers calculating water supply for such regions will usually be able to approximate the available water by comparison with the known records of other streams flowing through similar country. Estimates of the probable discharge and run-off to the square mile from the area drained by the stream under consideration can be based on previous records of other gaging stations on streams draining *similar* catchment basins. This run-off per unit of area multiplied by the area of the catchment basin under investigation gives the approximate discharge of that basin. To make such comparisons is safe only when the streams compared are in the same section of the country and drain similar areas.

In addition to the variation in intensity and distribution of the rainfall throughout the year, allowances must be made for differences in geological structure, topographical features, temperatures, barometric conditions, and surface areas of two basins. Many of the larger streams tributary to the shale regions have been under observation, for years, and records can be obtained by applying to the Director, U. S. Geological Survey, Washington, D. C., or to the various field offices of the Survey.

When discharge records at points below the contemplated shale plant site are available for a stream, the flow at the upstream site may be approximated by preparing a drainage map and determining the total area drained by the stream. The average run-off per square mile for the catchment basin can then be calculated. The approximate discharge of each tributary of the main stream in the basin can be obtained by multiplying the drainage area of the tributary by the average run-off per square mile. Then the approximate discharge of the tributaries emptying into the stream below the plant site may be subtracted from the stream flow given by the discharge records available, and the remainder can be assumed to be the water available at the plant site. For larger river systems such calculations and the run-off per square mile should be modified,

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if necessary, to allow for variations in the surface of the catchment basin and the different amounts of precipitation on the different regions drained by the streams and its tributaries. When the plant site is below the gaging station the approximate discharge may be obtained by adding, instead of subtracting, the approximate water contributed by the tributaries of the river above the plant site and below the gaging station.

TIME REQUIRED FOR COMPILING RELIABLE DATA ON STREAM FLOW.

Stream discharge records collected for a short time or for intermittent periods are unreliable. During a few days the increase from minimum to maximum flow may be several hundred per cent. Continuous records for 2 or 3 years are not to be trusted implicitly; even records of 10-year periods should not be relied on to show extreme low water or flood conditions.

SPRINGS AND WELLS.

Although it now seems probable that the majority of the shale plants and their industrial communities will obtain their water supply from the larger rivers and streams, many of the companies may get water from springs or deep wells. In part of the shale country the expense of developing an adequate uniform surface water supply may be prohibitive because of the cost of dams, the great difference between high and low water flow, the lack of easily developed storage facilities, and the cost of long pipe lines. Much rich shale also lies in high cliffs and on mesas where the cost of pumping water from the valley will be great. In nearly all of the Western States containing the larger oil-shale deposits, considerable shale lies five or more miles from the rivers and larger creeks. Some of these creeks are raging torrents during the spring and after heavy rains but are dry during other periods of the year. To insure uniform water supply for large plants and industrial communities from such streams, even when the total yearly run-off is large enough, will prove so expensive at many places that underground water supply will be utilized wherever possible. The development of an underground water supply, where local conditions favor its development, will be an individual problem for each plant, as the location, the size, and the water consumption of the plant and the community will have to be considered. In parts of the oil-shale districts there are many large springs; and it seems probable that in a number of localities enough underground water will be available, if developed properly, to supply the water necessary for a medium-size plant and for domestic use.

The amount of water continuously available from wells is more uncertain than the amount of run-off from a given catchment area, and practically every locality in the shale country will present a new

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problem. There is also a limit to the quantity of water that can be obtained constantly from a well, and this limit varies with local conditions. If one well yields a certain quantity of water it by no means follows that by drilling another well near the first the yield can be doubled. The capacity of a given well supply depends largely on the size of the exposed catchment area, the precipitation on this area, and the perviousness of the soil or underlying rock.

In some places it is necessary to use wells intermittently, allowing the adjacent soil to store up water. The water content of a saturated soil or clay may range from 10 to 40 per cent. When a well is pumped, water is drawn from the sides as well as from the bottom. By continued pumping the water level or hydraulic gradient is lowered near the well, and if the soil is of uniform porosity the hydraulic gradient takes the form of an inverted cone, having its apex at the well. If wells are so close that their hydraulic gradients intersect, the yield of each well will be reduced. Furthermore, it is necessary to sink the wells in a line across the direction of flow of the ground-water current, for if placed on a line in the direction of flow, the upper well will usually draw most of the water.

There is no way of estimating what will be the probable yield of a well except by noting the yields of other wells in the same locality, and even then the estimate is to be regarded as only an approximation.

In some wells the flow has diminished or completely ceased, because of the clogging of the inlet openings.

Numerous shallow and deep wells are in use in many localities adjacent to or in the oil-shale areas. Information relative to the yield a minute, height of water level, and quality of the water can usually be obtained locally, or from the United States Geological Survey.[17]

RECOVERY OF WATER FROM SHALE.

WATER CONTENT OF OIL SHALES.

Oil shale, like coal, contains water in two conditions or states: Moisture or free water, and combined or inherent water. No definite line separates these two states and, as a rule, the free water can not be extracted from the shale without also extracting some of the so-called water of combination. The combined water, before its extraction, differs from the free water in having a subnormal vapor pressure and requiring an energy change for its removal from the shale.

[17] Darton, N. H., Preliminary list of deep borings in the United States: U. S. Geol. Survey Water-Supply Paper 149, 1905, 175 pp.

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FREE WATER.

Oil shale, when separated from its free water or moisture, is fairly hygroscopic, and some shales are much more so than others. The table below gives the percentage of water absorbed by a few different shales. The samples used for these tests were not freshly mined but had been in the laboratory for five months to a year.

The samples were dried in an oven at 105° C. until, as nearly as possible, all the free water or moisture had been removed; the loss of water was calculated as a percentage and as gallons per ton. Then the samples were placed in separate tubes, boiled in distilled water for about 48 hours, and allowed to remain in the water for about 2 more days. Finally the pieces of shale were surface dried and immediately weighed. Dissolved salts, etc., were compensated for by evaporating to dryness the tubes containing the water in which individual shale samples had been placed and by noting the increase in weight of the tubes.

TABLE 4.—*Moisture content of shale.*[a]

Shale.	Loss due to drying.[b]		Final water content[c] after absorption.	
	Per cent.	Gallons per ton.	Per cent.	Gallons per ton.
Soldier Summit, Utah	0.640	1.544	2.372	5.680
De Beque, Colo. (massive)	.617	1.478	2.570	6.150
Green River, Wyo	.444	1.065	2.455	5.789
Dillon, Mont	1.700	4.070	4.620	11.103
Scotch shale	.818	1.958	3.460	8.280

[a] Laboratory work, by R. D. Howard, Department of Metallurgical Research, University of Utah.
[b] Calculated on original-weight basis.
[c] Calculated on moisture-free basis.

COMBINED OR INHERENT WATER.

Oil shale also contains combined or inherent water which is released during the retorting process. This water is held in the shale largely in the form of hydrated salts, such as sulphates and silicates, part or all of it is released when the temperatures of oil production are reached, and some may be formed by thermo-chemical action during the retorting process. The amount of water during any stage of the retorting process depends largely upon the character of the shale undergoing distillation. In some shales the combined water exceeds the oil yield, whereas others produce only a small amount of water. The curves in Figure 7 and Figure 8 show the water, oil, and gas yield for various shales undergoing distillation in a small electrically heated rotary retort where temperature conditions were accurately controlled throughout the shale mass.[18]

[18] Experimental data from L. C. Karrick, assistant oil-shale technologist, U. S. Bureau of Mines.

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NATURE AND PURIFICATION OF WATER RECOVERED DURING RETORTING PROCESS.

The writer is deeply indebted to certain companies,[19] specializing in water-purification problems, who have given detailed advice and information on the subject, much of which is included in this and the following sections.

Considerable water can be recovered from the free and combined water in the raw shale. (See Table 4 and Figs. 7 and 8.) This water may be suitable for certain purposes at an oil-shale plant, and may sometimes be used in regions where the natural supply of water is

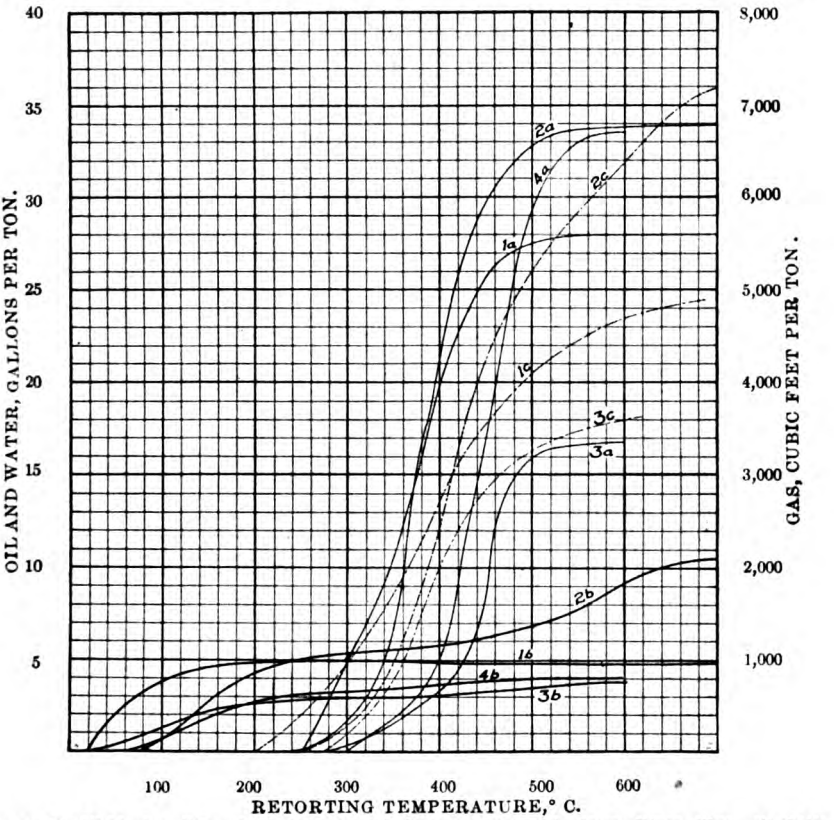

FIGURE 7.—Yields for different oil shales: *a*, Oil; *b*, water; *c*, gas; 1, Green River, Wyo., oil shale; 2, cannel coal from Kentucky; 3, Kentucky oil shale; 4, Duchesne, Utah, oil shale. Same scale used for oil and water.

small. The water recovered when oil shale is retorted contains in solution and suspension considerable material injurious to boilers and other equipment. Such water will have to be treated before use. In some places and for some shales where the recovered water is used merely to supply steam for the retorts, and where suitable

[19] The Dorr Co., engineers, New York City; Wheeler Condenser & Engineering Co., Carteret, N. J.; American Water Softener Co., Lehigh Avenue and Fourth Street, Philadelphia, Pa.; The Permutit Co., New York City; Wm. B. Scaife & Sons Co., Oakmont, Pa.; Refinite Co., Omaha, Nebr.

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methods for preheating the shale are employed, it may not be necessary, although probably advisable, to treat this water chemically. A possible use of this water for oil condensers has been suggested on page 25. For general power and boiler use the water recovered from the retorts will have to be treated, because it is contaminated with substances unusual in natural waters. Treating the water from the shale retorts to make it satisfactory for industrial and domestic uses

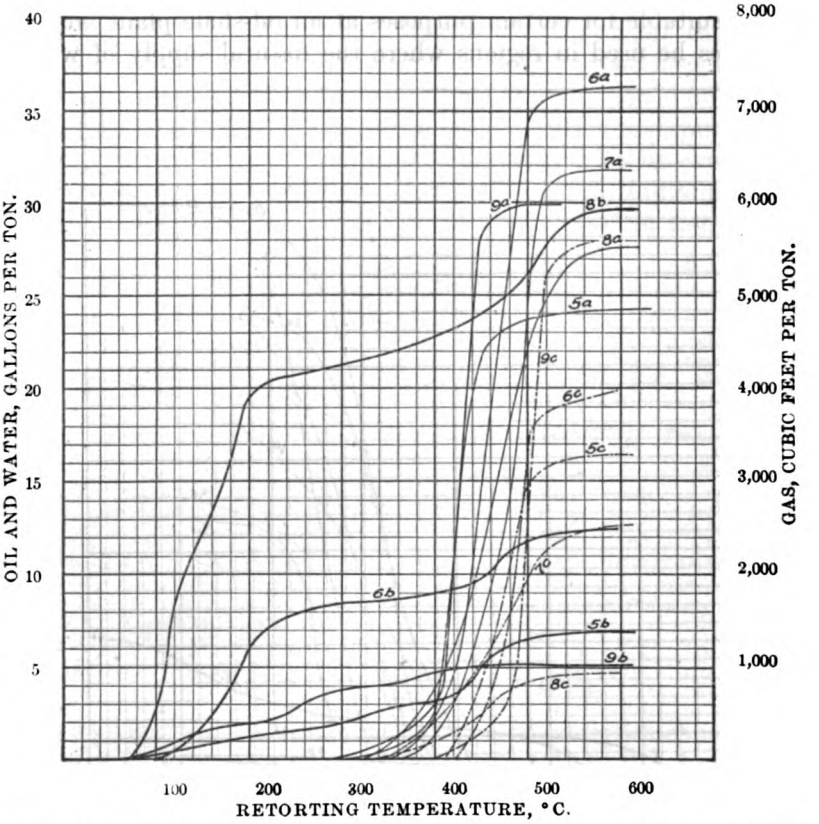

FIGURE 8.—Yields for different oil shales: *a*, Oil; *b*, water; *c*, gas; 5, De Beque, Colo., oil shale; 6, shale from property of Western Shale Oil Co., Dragon, Utah; 7, Scottish oil shale; 8, shale from property of Catlin deposits, Elko, Nev., average across face; 9, De Beque oil shale, from Mount Logan, Colo. Same scale used for oil and for water.

will be difficult and expensive. The cyanogen compounds in particular are practically permanent, and their reduction and removal will usually be costly.

Samples of water recovered from oil-shale retorts in the laboratory were submitted to a few of the different companies specializing in water purification in the United States and after treatment the water, although perfectly clear, still had a strong odor and was entirely unfit for domestic consumption.

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One company [20] gave the information that follows:

The water in question is naturally a difficult water to treat, either to make it suitable for domestic or for industrial purposes, such as for boiler feeding. Even after treatment we do not believe that the water in question would be suitable for potable purposes; however, for domestic purposes, such as washing and bathing, it could be used after treatment.

We treated in the laboratory a small sample of the water, the treatment consisting of applying heat, precipitating a part of the total solids in the water and distilling the water.

The probability of treating such water economically is remote—however, the water can be rectified so as to make it possible for use in homes and boiler plants, with the exception of making it desirable for drinking; but such a treatment certainly would be expensive and the apparatus involved more than likely would be prohibitive in first cost.

The following excerpt from a letter from another company [21] is of interest:

The cyanogen compounds in particular are practically permanent and their reduction and removal would not be accomplished with ordinary expenditure. Water contaminated with the substances mentioned is so far removed from water with impurities characteristic to natural supplies that we do not attempt the purification of such waste waters, for in practically all cases the expense involved is too great.

Another company [22] wrote as follows:

Lime-soda treatment may be used to greatly improve and purify such waters as you describe, especially when the treatment is combined with aeration and later filtration.

The treatment in general consists of blowing air through a tank of the water, then adding lime-soda, agitating and settling. The clear liquid standing above the precipitate produced by the lime-soda is then drawn off and filtered. The effect of agitation of air is to oxidize many of the substances present, such as hydrogen sulphide, and change them into a less obnoxious form. Many of them are carried down with the precipitate formed on the addition of the lime-soda and the water thus purified, as well as softened. The filtration renders positive the clarification of the water and serves to remove further the impurities present.

Analysis of an average composite sample of the water recovered during retorting runs, where steam was passed into the retort in a quantity large enough to allow equal volumes of oil and water to be condensed is as follows [23]:

TABLE 5.—*Analysis of water recovered during oil-shale retorting.*

[Analysis of the water decanted, 2½ gallons.]

Turbidity, —; color, dark yellow; odor, strong sulphide; Solids at 110° F., 532 parts per million; solids after ignition, 144 parts per million; $(NH_4)_2S$, 1,920 parts per million.

Determination.	Parts per million.	Determination.	Parts per million.
Total hardness as $CaCO_3$	30	Chlorides as Cl	7
Calcium hardness as $CaCO_3$	.....	Sulphates as SO_3	50
Magnesium hardness as $CaCO_3$	.....	Iron as Fe	0
Alkalinity, methyl orange, as $CaCO_3$	3,200	Manganese as Mn	0
Alkalinity, phenolphthaline, as $CaCO_3$	700	Silica as SiO_2	.....
Causticity as $CaCO_3$	0	Permanganate consumed as $KMnO_4$	2,500
Free carbon dioxide as CO_2	0	Oxygen dissolved as O_2	.....

[20] The Permutit Co., New York, N. Y.
[21] William B. Scaife & Sons Co., Oakmont, Pa.
[22] The Refinite Co., Omaha, Nebr.
[23] Analysis by the Permutit Co.

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PURIFYING NATURAL WATER SUPPLIES.

In some shale regions the natural water supply contains a large proportion of substances that should be removed before the water is used. The water should be submitted to thorough chemical analysis and the type of treatment selected that will prove most satisfactory. Methods suitable for treating one water may not be suitable for another of different analysis. The treatment varies with the nature and the percentage of foreign substances present in the raw water and the purpose for which the water is to be used. To use hard untreated water in a boiler causes unnecessary waste of fuel, because the scale deposited by the water retards the flow of heat from the furnace into the boiler and, if the coating of scale becomes thick, much heat is wasted up the stack.

Practically all natural waters contain more or less foreign material; some of this, as clay and insoluble forms of iron and aluminum, is in suspension; some of it, as soluble compounds of magnesium, calcium, sodium, potassium, and other elements, is in solution. Much of this material, if present in appreciable quantity, should be removed before the water is used in plant operations. Water for a boiler should have the bicarbonates and sulphates of calcium and magnesium removed, as these are the most important scale formers. Waters containing in solution bicarbonate of calcium or magnesium or both are of temporary or carbonate hardness, and waters containing dissolved calcium or magnesium sulphate or both are of permanent or sulphate hardness.

Water that contains carbonates chiefly may be much improved for boiler use by passing it through open heaters of the exhaust-steam type, but waters containing appreciable amounts of sulphates are seldom amenable to this treatment.

For general plant and power use, the advantages of soft water are so numerous that the expenditure necessary for softening it is ordinarily justifiable.

DISTILLATION AND EVAPORATION.

One of the best methods of obtaining absolutely pure water is by evaporation and condensation (distillation). As a rule, however, water of such high purity is seldom required in average commercial practice and at many plants the cost of this method of purification prohibits its use.

Where large quantities of heat may be wasted, as in flue stacks, hot spent shale, and heat exchangers, it will probably be possible at many plants to utilize this heat in distilling water for special purposes. The hot flue gases may be allowed to come into direct contact with the water-containing vessel, or they may pass through pipes or coils immersed in the water, or come in contact with pipes

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containing circulating water. The water pans or pipes may be several yards in length and may contain only one large flue, or several small ones, according to the work desired; but such apparatus is usually expensive to build and difficult to keep in repair.

In a number of water-evaporating installations vacuum systems are employed, which are very efficient, especially the two or three stage systems. Vacuum methods of distilling water will rarely be required at most shale plants, and for this reason they will not be discussed.

FILTRATION.

Filtration is often applicable, especially if the water contains a large amount of suspended solid matter or matter that can be coagulated. Under proper conditions filtering removes from the water all turbidity and practically all bacteria. The amount of decoloration by filtering is determined largely by the impurity giving the color. Water-softening processes are seldom satisfactory unless the amount of suspended matter is reduced to a minimum. At many places water containing free acid can be treated by filtration through marble, limestone or other easily decomposed carbonates. Water that is clear, but is stained by decaying vegetation and requires treatment for the removal of bacteria, may often be purified satisfactorily by slow filtration through sand. To remove all coloration a coagulant (alum, for example) is added to the water and the coagulated coloring or staining substances, are removed by sedimentation and filtration. Filtration is difficult if the water contains much fine, slimy precipitates, or forms crystals in the interstices of the filtering material.

For ordinary use at many places a sand filter with downward flow will prove satisfactory. Such filters when constructed properly are not expensive to install or maintain.

CHEMICAL TREATMENT.

Two general types of filters are used for softening water by chemical action—zeolite and precipitation.

ZEOLITE FILTERS.

In zeolite filters the water is forced through the filtering medium by pressure. The filtering medium (zeolite) is usually a hydrous silicate of aluminum containing a large amount of chemically active sodium. When water containing salts of calcium and magnesium passes through a zeolite filter, the sodium is exchanged for the calcium and magnesium and the effluent contains only a small amount of these substances. During use the zeolite gradually exchanges most of its sodium for the calcium or magnesium in the water undergoing treatment until the filter ceases to be effective. Then the

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filter bed is soaked in a strong solution of brine made of common salt. The calcium and magnesium that have been absorbed by the zeolite from the boiler water are exchanged for the sodium of the sodium chloride, forming calcium and magnesium chlorides, and the sodium is absorbed by the zeolite. After the zeolite has been regenerated, the brine is drained from the filter, the remaining free salt washed out with water, and the filter is ready for another cycle of operation.

SOFTENING WITH LIME AND SODA ASH.

Two general classes of water softening methods using soda ash are in use to-day, the intermittent and the continuous.

INTERMITTENT TYPE.

Lime and soda-ash water-softeners of the intermittent type usually have two or more tanks which are used alternately. One tank is filled with raw water, the required amount of chemicals is added, the water agitated to insure thorough mixing with the reagents, and the precipitate is allowed to settle. During this period the water for operating the plant is drawn from another tank. The number and size of the tanks should be such as to allow sufficient time, during peak demands, for the precipitate to settle. Continuous thickening or sludging tanks for water treated with lime, or lime and alum, have also given satisfaction, thus making the above-mentioned process practically continuous.

CONTINUOUS TYPE.

In the continuous type of lime and soda-ash softener, a large sedimentation tank is used. The capacity of this tank is three to six times, averaging about four times, the hourly demand for water. The required amount of chemicals is mixed, in reagent tanks, with enough water to allow the solution to be readily handled by an apportioning device that feeds it at the proper rate into the raw water. The solution and the raw water are usually mixed by flowing into a down-take, where much of the precipitation takes place. After passing through the down-take, the water rises slowly in the sedimentation tank and overflows, then passes upward through a suitable filter. The area of the filters is such that the water does not move upward fast enough to prevent the free downward movement of the precipitates, which settle to the bottom and are drawn off as often as is necessary.

BOILER COMPOUNDS.

If enough good water can be obtained for domestic use and, if the shale plant is small and obtains its water from other sources, boiler compounds may be used to treat the water required for steam making.

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CHOICE OF METHODS.

Careful study and consideration of the suitability of different types of equipment for use with the water available should be made by competent engineers in every individual case. Equipment entirely suitable for one locality may prove ineffective at another.

DOMESTIC WATER SUPPLY.

Many of the impurities in water are objectionable, and water containing no physiologically injurious bacteria or impurities may be objectionable because of its color, turbidity, odor, or taste. Ordinary hardness is objectionable in water for laundry and household uses. Decaying vegetable matter or the growth of algæ in the reservoir may cause pronounced odor and taste. Some water may have a bad odor from sewage or the wastes from manufacturing plants. The water recovered during the retorting of shale has a very objectionable odor, even after chemical treatment, and is likely to contaminate a water supply.

PRELIMINARY CALCULATIONS FOR DOMESTIC WATER SYSTEMS.

As an aid in checking water-supply data for preliminary estimates, tentative designs and layouts of shale plants, the information given below may prove of use.[24] It should not, however, be used in designing small waterworks and water-supply systems until careful consideration has been given to local conditions.

The equations are for cost data on centrifugal pumping units for 125-foot, 175-foot, and 250-foot heads. These units include 3-phase 220-volt, 1,800-r. p. m. squirrel-cage, alternating-current induction motors, complete with hand-operated starting compensators, mounted on the same subbase and directly connected to the pumps. The costs are f. o. b. works and are as of April 1, 1919.

COST OF PUMPING UNITS.

Capacities from 500 to 1,500 gallons per minute, 250-foot head: Cost=$800+$1.25× g. p. m. (gallons per minute).

Capacities 250 to 1,500 gallons per minute, 175-foot head: Cost=$800+$0.80× g. p. m.

Capacities 100 to 750 gallons per minute, 125-foot head: Cost=$640+$0.75×g. p. m.

Capacities 750 to 2,000 gallons per minute, 125-foot head: Cost=$860+$0.45× g. p. m.

Similar cost equations for motor-driven rotary pumps of first-class manufacture are:

Capacities 100 to 400 gallons per minute, 125-foot head: Cost=$4.50×g. p. m.

Capacities 500 to 2,000 gallons per minute, 125-foot head: Cost=$1,300+$1.60× g. p. m.

[24] Ewing, D. D., Some cost and operating data for small waterworks: Engineering and Contracting, Oct. 13, 1920, vol. 54, p. 379.

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For air pumps with motor-driven compressors the equation is: Capacities up to 500 gallons per minute, 50-foot lift: Cost=$500+$4×g. p. m.

For motor-driven deep-well reciprocating pumping units the equations are:

Capacities up to 200 gallons per minute, 160-foot head: Cost=$600+$9×g. p. m.

For elevated tanks, height to top of tank 100 feet, tank capacities 25,000 to 200,000 gallons: Cost=$3,200+$45×(capacity, in 1,000 gallons).

The tank costs are for the tanks erected complete and include everything except freight charges. The weights of these tanks and their towers are given by: Weight= 14 tons+$\frac{1}{4}$×(capacity, in 1,000 gallons).

Standpipe or tank capacities in gallons and the populations for small Kansas communities, the equations are:

Capacity (average)=35,000+(36×population).

Capacity (minimum)=30,000+(5×population).

For towns under 1,500 population, a 50,000-gallon tank, mounted on a 100-foot tower, is a very common installation.

For pneumatic tank systems, Kansas practice indicates that the tank capacity= 12,000+(5×population).

A fair figure for the storage capacity needed in an ordinary Middle West town is probably given with a fair degree of accuracy by the equation: Tank capacity= 25,000+(35×population).

In many mining communities not enough water is provided for domestic use; the effects on personal hygiene and camp sanitation are degrading. Many camps are being compelled to rebuild and relay distributing systems because the equipment installed at first was inadequate. Much of the cost of providing the additional water requirements incident to camp growth may be avoided by proper planning of the camp or community site and by giving especial care to the distribution of water mains.

In designing water mains it is necessary to provide for peak loads, unless the water is to be delivered to small distributing reservoirs with capacities sufficient to compensate variations in consumption. For average domestic consumption, the maximum daily rate ranges from one and one-half to two times the average daily rate, and the maximum hourly demand is often two and one-half to two and three-fourths times that of the average hourly rate.

FIRE PROTECTION.

Fire service should receive special attention. In general, small communities do not have fire engines, and the water-distribution systems should be able to deliver water under a pressure of 30 to 35 pounds per square inch at the hydrants with a flow of 150 to 250 gallons per minute. If possible, hydrants should be placed so as to allow the concentration of two or three streams on any one spot without the use of hose lengths greater than 350 to 600 feet. Usually the water requirements for fire protection will determine the allowable loss of head and will fix the size of pipe in the distributing system. Of course the water used for fire protection need not be suitable for domestic use, but it should not injure the pumping and distribution system.

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GENERAL ENGINEERING AND SANITARY CONSIDERATIONS.

DISPOSAL OF WASTE WATER.

At some places in this country it may be permissible to allow the waste waters from a retorting plant to run over adjoining land with possible benefit to the soil. (See p. 12.) Generally speaking, however, the raw waste waters will be detrimental if emptied into streams, and it seems probable that some method of treatment will have to be used. In Scotland the shale operators let the waste water trickle over spent-shale "bings" before wasting, probably for filtration and for purification by aeration.

EFFECT OF WEATHERING OF SPENT-SHALE DUMPS ON WATER SUPPLY.

Vegetation is sparse in much of the shale region of the West and the run-off there is high. During precipitation little water is stored in the ground or held back by vegetation; as a result many of the small creeks and dry watercourses become swift-flowing torrents during periods of even moderate rainfall. Preliminary plans of many shale companies contemplate dumping the spent shale down the slope below the retorting plant. Probably most of the plants will be situated on the sides of ravines or on canyon walls, the shale moving by gravity to the retorts and then down the slope. Probably, also, this arrangement will prove economical with regard to certain engineering considerations and will be used at many plants; but, because spent shale weathers easily, care should be taken to avoid trouble with drainage and water supply. Rapidly flowing water readily moves disintegrated spent shale and holds it in suspension until the velocity has decreased to a few feet a minute.

One of the outstanding problems of the Scottish shale plants is the disposal of spent shale. In this country the problem will be simpler because topographic conditions are generally more favorable, but at many plants it will be impossible merely to dump the spent shale down the hill. Oil shale yields 45 to 90 per cent of residue, about 65 per cent on the average, and a large plant will accumulate an enormous body of spent shale in a comparatively short period. Particular consideration will have to be given to preventing the pollution of streams. The Scottish shale dumps give off a disagreeable odor, probably caused by compounds of nitrogen, cyanogen, and sulphur. The water draining from the dumps carries in solution a considerable amount of soluble salts and compounds.

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PRIVIES.

Wherever possible, privies and outhouses should be condemned and barred from the shale plant community. Typhoid fever, hookworm, and diarrhea are disseminated by careless disposal of fecal discharges. The ideal way of disposal is a proper sewage system, but at small temporary and construction camps the cost of a sewage system may be prohibitive. In some communities and many temporary camps the privies are so built that urine and feces, through the agency of insects, animals, rain, and wind, may pollute near-by shallow wells. Such a condition should never be permitted; it means a direct loss to the inhabitants of the camp and to the company.

CONSTRUCTION.

A form of privy successfully used in many camps has a watertight, preferably metal, container and a convenient box of lime or dirt for covering the excrement and thus minimizing foul odor and the danger from the transmission of disease by flies. The receptacles should be emptied at least once a week during the cooler months and about twice a week during the summer. In a form of privy successfully used by the Utah Fuel Co. at the Castle Gate Mine[25] the fly-proof building stands over a concrete vault, which has an outside self-closing, tightly fitting, clean-out cover. The vault is emptied regularly by a special truck provided with a 4-inch suction hose—a cheaper and more sanitary method than the use of containers. The windows of the building are screened, the floors are built from matched flooring, and the seats have self-closing, tightly fitting covers. The two ventilators—one in the roof and the other extending from the vault to the roof—are each covered with wire screens.

If privies are allowed in the community, the operating company should maintain a regular scavenger service, and the waste material should be hauled to an incinerator or to a place where it can be buried without causing a nuisance or polluting the water supply.

The oil-shale industry, one new to this country, will need to keep its workers, and hence should seek to establish living conditions that will be attractive. Although most of the shale plants are in the semicommercial and experimental stage, yet a visitor can see that at only a few have future plant layout, expansion, and sanitary conditions received proper study.

As the largest deposits of oil shale in this country are in sparsely settled mountainous regions, many shale companies will have to lay out town sites and build houses. In this work the larger companies should seek the advice of the landscape architect, the sanitary engineer, and the building architect, as well as that of plant and construction engineers.

[25] Courtesy of Mr. J. P. Russell, engineering department, Utah Fuel Co.

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RELATIONS OF PLANT TO TOWN SITE.

Building the town near the plant simplifies the shipment and hauling of building material and reduces the cost of supervision; it may lessen charges for heating, lighting, water supply, sewage disposal and fire protection, and may avoid the possibility of litigation about roads, power-transmission lines, and water pipes. To house employees near the plant is also advantageous because men occupying responsible positions are available for immediate call. Shale retorting plants and the spent-shale bings will probably give off obnoxious odors (largely due to hydrogen sulphide). For this and other reasons it will probably be desirable to have dwellings a short distance from the plant itself. If suitable land is available, the town may be laid out as a whole, with houses suitably placed. The importance of town-site layout and of proper sanitation is discussed in more detail by Doctor Murray on pages 51 to 57.

LAWS GOVERNING USE AND POLLUTION OF WATERS.

An excerpt from a report of the United States Geological Survey,[26] presented below, summarizes the common and statute law on the use of water:

The common and statute laws governing the use of water may be summarized and stated in a few general rules, which will perhaps be useful to property owners and also to officers charged with the duty of protecting health and property rights in waters.

In the nature of the case these rules can only be general, and many exigencies will appear in which more particular instructions must be obtained from the consultation of textbooks and decisions or from the advice of counsel.

RIGHTS AND DUTIES OF RIPARIAN OWNERS—CLASS 1.

Every riparian owner has the right—

1. To use the waters of streams, navigable or otherwise, which flow across or along his property for the ordinary purposes incidental to domestic life and agriculture, including grazing.

2. To use such waters for water power and for all kinds of manufacturing purposes which do not sensibly diminish the quantity which flows on for the use of lower proprietors nor change the quality of the waters to any appreciable extent, nor interfere with the use of the stream, if navigable, by the public.

3. To have such waters flow to him from the premises of higher proprietors not unreasonably diminished nor diverted nor rendered impure by the farming or domestic uses to which the waters are subjected by higher proprietors.

4. To have such waters flow to him not sensibly changed in quality by any manufacturing or other uses to which they may have been put by higher proprietors.

5. To have such waters flow to him in their natural bed, unpolluted by any deposits of filth or any other substance in the bed or channel previously traversed by them. But 3, 4, and 5 do not apply to riparian owners in those States in which the doctrine of prior appropriation is the law.

[26] Goddell, E. B., A review of the laws forbidding pollution of inland waters in the United States: U. S. Geol. Survey Water Supply Paper 103, 1905, pp. 141-144.

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Conversely, it is the duty of every riparian owner:

1. To so guard his use of the waters of streams which flow across or along his property for domestic and agricultural purposes as not unreasonably to divert nor diminish nor render impure such waters.

2. To refrain from every use in manufacturing which will divert or sensibly diminish the quantity of the waters which flow onward to the lower proprietors or render them appreciably different in quality.

3. To refrain from depositing any filth or other substance in the bed of such streams in such a manner or to such an extent as will cause the waters to flow to the lower proprietors out of their natural bed or will in any wise pollute them or render them impure.

Where the doctrine of prior appropriation is in force the appropriator must confine his use of the appropriated water to the use for which he has appropriated it and take only so much as is reasonably necessary to accomplish that purpose. He may not pollute the stream wantonly, nor use it for purposes not included in his appropriation. Subject to these restrictions, the prior appropriator has the right to divert from the stream and use as much of the water as is necessary to accomplish the purpose for which it was appropriated.

RIGHTS AND DUTIES OF MUNICIPAL CORPORATIONS—CLASS 2.

Considered as corporate entities, municipal corporations have such rights and powers only as are conferred upon them by statute, either expressly or by necessary implications.

When, under due authority, they become the owners of lakes, reservoirs, and natural streams, they have the same rights to pure water and are charged with the same duties as are other riparian proprietors.

If authorized to construct a system of sewers draining into a stream, such authority does not exempt them (except in the State of Indiana) from the duty not to pollute the stream to the damage of lower proprietors.

The rights of property owners specified in 3, 4, and 5 above are property rights and can not be taken away from owners for public use except upon payment therefor of an amount determined by constitutional condemnation proceedings authorized by statute.

Therefore, until municipal corporations have, by such proceedings acquired the rights of all lower proprietors and paid for them, they are required in all cases to refrain from the pollution of streams to the same extent as private owners.

RIGHTS AND DUTIES OF THE PUBLIC—CLASS 3.

By "the public" is meant that indefinite number of individuals, whether larger or smaller, who occupy as a common habitation a neighborhood village, town, State, or county. Rights and duties which affect inhabitants of the neighborhood, village, town, State, or country as a whole, or a considerable but indefinite number of them, are called "public" rights and duties.

The public, in this sense, aside from the right to use navigable waters for commerce, has the right to enjoy the natural waters and the air which passes over them, so far as life and health are affected by these elements, in a condition so near that in which nature left them that their use will not destroy nor threaten life nor injure health.

And, reciprocally, the public, and each member of it, is charged with the duty not to pollute the natural waters upon which the community depends for life and health in any manner that will render the continued use of the waters, or of the air which passes over them, destructive of or injurious to the life or health of the community.

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PUBLIC RIGHTS AND DUTIES ENFORCED BY STATUTE.

The rights and duties attempted to be expressed under class 3 have received some recognition by the courts apart from statutory enactments. They have been enforced chiefly, however, through legislation. These rights and duties have received full recognition, and an active effort has been made to provide an efficient sanction for their enforcement by the legislatures of all the States included in class 2 and class 3, as hereinbefore stated. These classes include 30 of the States and Territories.

These statutes, not being in derogation of common-law rights, have been construed as remedial statutes and not unconstitutional, although in some cases they may seem to interfere with prescriptive rights. No one can acquire by prescription a right to do an act which menaces public health or destroys public comfort.

PROGRESS OF LEGISLATION.

It will have been noticed that public opinion, as expressed in public law, is steadily progressing in the direction of a full, complete, and comprehensive enforcement of all rights and duties of riparian owners, of municipal corporations, and of the public, as summarized above. Each advance in statutory regulation is an advance in that direction, and more especially in the direction of regulating and enforcing public rights and municipal rights and duties.

Private owners, from time immemorial, have been active in protecting their riparian rights as against other private owners. But the effect of pollution upon public health has not, until a comparatively recent period, been brought prominently into notice. The pollution of streams by cities and private persons has, accordingly, not received the attention which it deserved. This state of affairs is now rapidly passing away. Courts have shown themselves fully alive to the existence and validity of public rights in that respect, and the legislatures of class 3, comprising the States of Connecticut, Massachusetts, New Hampshire, New York, New Jersey, Minnesota, Vermont, and Pennsylvania, which has come into this class by legislation enacted in 1905, have made enactments calculated so to control such pollution as eventually to prevent all danger to public health.

UTAH REGULATIONS.

Questions submitted by the writer to Mr. C. J. Ullrich, deputy State engineer (1921) of Utah, and the answers received are as follows:

1. On streams where the water has already been entirely taken, during the irrigation season, how may a new company secure the right to use water from these streams for its plant and for domestic use?

Where all the water of a stream has been appropriated during the irrigation season, a right to the use of such water for industrial purposes can only be secured by purchase, or making other satisfactory arrangements with some party already having an established right on the stream.

2. Can the company purchase a certain amount of water from parties who already have the right to use this water for irrigation, and use it for their plant operation? In such a case would industrial purposes have the preference over irrigation?

A company has the right to purchase irrigation water and use it for industrial purposes; however, before such change of nature of use will be allowed, the company will have to file an application for change of point of diversion, place and nature of use, the same to be advertised and approved by the State engineer. Water for industrial purposes does not have preference over water for irrigation purposes.

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3. In the event that users of water refuse to sell, for a fair price, a portion of their water, how can this new shale company requisition, or in some other way secure, the necessary water for its use?

Where water users, having the right to the use of water for irrigation purposes, refuse to sell their right or part of their right for industrial purposes, I know of no way that a company can acquire water, provided the water in the source of supply is all appropriated, for the reason that the law considers water for irrigation purposes a higher use than for industrial purposes.

4. Can you give references to similar cases and any laws relative to this subject?

I can not give reference at the present time of any laws or court decisions covering the appropriation of water for oil-shale purposes outside of the statute laws of the various States providing that unappropriated water may be appropriated for miscellaneous purposes.

5. What are the regulations governing the discharging of plant wastes and sewage into streams used for irrigation and city water supply? Will it be necessary for the industrial communities around the contemplated shale plants to treat their sewage before discharging into the river?

There are no specific laws in the Utah statute books governing the discharge of industrial plant wastes and sewage into public streams; however, should the discharge of sewage and industrial wastes become obnoxious or detrimental to water users of said stream or to the public health, the same may be abated as a nusiance under the police powers of the State, counties, and municipalities. As to whether industrial communities around oil-shale plants will have to treat their sewage before discharging the same into public streams, it depends entirely upon the nature of the sewage and the degree of dilution.

6. Is it necessary for a new company to purchase the water rights for the entire year or only during the irrigation season when the peak demand for water exists?

Where the entire stream flow the year round has been appropriated, it would be necessary for a company needing water for industrial purposes to purchase such water for the entire year. If, on the other hand, there is unappropriated water in the source of supply during the nonirrigation season, then such unappropriated water may be acquired by appropriation through this office during such period of the year as it is unappropriated.

7. Can you furnish data giving the amount of water already decreed for irrigation purposes on the streams of Utah, the amount of land under irrigation, and the principal districts where irrigation is used in Utah?

The amount of water decreed for irrigation purposes on the various streams of Utah can not be given, as there are practically no streams within the State to-day on which there has been complete adjudication of water rights; neither can the information relative to the total amount of land irrigated at the present time from the various streams as such a determination has not to date been made on any stream or river system.

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COLORADO INTERSTATE DIVERSIONS.

Future demands and decrees for water on the Colorado River below the Colorado line can not be foretold at the present time, but the following statement[27] may be used as a criterion:

The rights of various claimants upon interstate streams should and doubtless will be settled by interstate compacts between the States, with the consent of Congress, as permitted by the Constitution of the United States.

Pending interstate compacts, it is important that Colorado streams should not be burdened with perpetual servitudes which are foreign to Colorado territory and that the waters of this State should not be appropriated for the benefit of foreign territory.

Our constitution declares that the water of every stream within the State is "the property of the public" or State, and these waters are "dedicated to the use of the people of the State" and not to the use of the people of other States.

The State courts have uniformly held that our streams are for the use of the people of this State, free from external interference and foreign servitudes. That there might be no further question, the legislature in 1917 passed an act (S. L. 1917, ch. 151, p. 539), modeled after the New Jersey act, construed in Hudson County Water Co. *v.* McCarter, 70 N. J. Eq. 698, 209, U. S. 349, as prohibiting interstate diversions. Any interstate compacts would modify this act, but until such are adopted the State engineer is bound by the terms of the act.

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[27] Nineteenth Biennial Report of the State Engineer of Colorado, 1917–1918, p. 20.

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SANITATION OF OIL-SHALE CAMPS.

By A. L. MURRAY.[28]

Oil-shale camps are peculiarly favored, inasmuch as it can be ascertained with a degree of certainty before they are established that they can be built to last. Unlike metal mines, where the metal content of a given area may be unknown until after years of development, oil-shale camps from the outset can and should be planned and built for permanence, so that they will serve the needs of the industry better and the cost of their care and upkeep will be less.

SELECTION OF CAMP OR TOWN SITE.

The site of the camp or town, whether or not on company property, should be selected with care. If possible it should be separate from the plant site in order to be free from noise and fumes and to provide a change of environment for employees. The main features governing the site to be selected are as follows:

DRAINAGE.

The general contour of the surrounding country should be such that drainage is away from the site. The camp or town if practicable should be situated on higher ground than that in its immediate vicinity.

SOIL.

The nature of the soil on which the camp or town is located may bear a decided relation to the health of the community. A porous, well underdrained top soil of at least 4 feet in depth insures dryness and facilitates the placing of foundations and the laying of water mains and sewer pipes. In addition, such a soil is an advantage in growing trees, shrubs, and grass plots, a decided adjunct to making the community attractive.

ENVIRONMENT.

The contiguous territory should afford no unwholesome surroundings such as swamps or accumulations of stagnant water.

GENERAL CONSIDERATIONS.

The provisions for water supply and for disposal of waste influence, to a certain degree, the selection of the camp or town site. The means of supplying water whether by gravity or by pumping, and the disposal of sewage whether by outfall system, septic tanks, broad irrigation, filter beds, or cesspools, will govern the selection of the site topographically in relation to the source of water and point of disposal of sewage.

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[28] Mine Car Surgeon, U. S. Public Health Service. This section was first published as Sanitation in planning and developing oil-shale camps, Reports of Investigation, Serial No. 2265, Bureau of Mines, July, 1921.

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PLANNING OF CAMP OR TOWN SITE.

A camp or town if worth building at all is worth building well. A definite plan for the utilization of space should be worked out and followed. In laying out the site, it should be remembered that successful undertakings progress and liberal allowance should be made for expansion. The area set apart for the camp or town should be ample and the general scheme of arrangements should be such that growth or expansion can be accomplished along preconceived lines so as to harmonize with the elements first erected.

A good plan to follow is to set apart one section somewhat central to the site selected, as a community center where the shops, churches, schools, and amusement halls may be built. Then after reasonable space has been allowed for recreation, such as play grounds for children and an athletic field for adults, the remainder of the site can be subdivided into lots suitable for boarding houses, apartments, and dwellings.

A system of highways of an established width with definite building lines greatly improves the appearance of camps or towns and helps much in extending sewer and water service. Where the contour of the site is such that various elevations are encountered, terracing at regular intervals permits an attractive arrangement.

WATER SUPPLY.

TOWN REQUIREMENTS.

The water supply for a camp or town is of grave importance and demands careful study. The prime considerations in selecting a water supply are purity and adequacy at all times. Seasonal variations in quantity should be noted and the amount available during dry seasons should be ascertained. The growth of the community should be considered, for it is far cheaper to provide for growth when installing the original system than to construct an entirely new one later.

The per capita daily consumption of water in large cities varies considerably, as may be seen from the following tabulation:

Per capita consumption of water in large cities.

UNITED STATES.

City.	Year.	Gallons per capita daily.	City.	Year.	Gallons per capita daily.
Pittsburgh	1905	250	Pittsburgh	1912	236
Chicago	1900	190	Chicago	1913	218
New York	1902	129	New York	1915	66
Worcester	1900	70	Worcester	1915	84
Fall River	1905	37	Fall River	1915	53

FOREIGN.

London	1912	36	Berlin	1913	24
Amsterdam	1905	37	Dresden	1905	26

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These figures can not be taken as an index for small communities, as the per capita consumption of some of the cities include water used for industrial or commercial purposes. In several of the cities, the amount of water used by industries is considerable. A fair standard of the average per capita requirement of water for domestic purposes follows:

Water needed for domestic use.

	Gallons.
Drinking and cooking	2
Bathing	8
Laundry	12
Toilet (water-closets)	8
	30

In the interest of health and sanitation, the per capita allowance should be as liberal as possible; it had better be considerably more rather than the least bit less than what is necessary.

SURFACE WATER AND GROUND WATER.

Sources of supply may be classified in two main groups—surface water and ground water. Surface waters include rivers, creeks, lakes, and ponds, while ground water is derived from wells and springs. Naturally the selection will be governed by the sources available within a reasonable distance of the camp or town, and by such considerations as freedom from pollution and supply by gravity flow or by pumping.

No source of supply should be selected until by careful testing the water is proved free from pollution. An exception may be made when the only supply available is one in which the pollution is slight and suitable provisions are made to purify the water by filtration or chlorination.

Surface waters are more subject to pollution than ground water. If a river, creek, or lake be selected, the watershed should be carefully guarded to prevent pollution by human and animal excrement. No stream draining an inhabited region should be considered as a source of domestic water supply unless a dependable method of purification is to be provided.

Ground water taken from protected wells and springs is less liable to pollution than surface water, but it frequently has the disadvantage of limitation in quantity. When wells and springs are used they should be kept free from surface contamination.

The method of supply, natural flow or pumping, will depend on local conditions. If possible, provisions should be made for a well-protected reservoir wherein a reserve sufficient for several days' supply may be always available. This water should not be stored,

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but the reservoir should be merely a holding basin between the source and the community system.

Whatever the source of supply, the health of the community demands that tests for impurities be made at frequent and regular intervals.

SEWAGE DISPOSAL.

Sewage consists of all liquid refuse from the household, including waste water from bathing, cooking, laundering, and the flushing of water-closets. Its volume about equals the per capita consumption of water, ranging from 10 to 50 gallons daily.

Sewage is the greatest menace to community health; hence wholesome sanitation demands its proper disposal, which should be as speedy as possible and cause the least nuisance. No camp or town can be considered abreast of the times if it lacks some reasonably safe method of sewage disposal. The type of sewage-disposal system to be adopted for any community will depend on local conditions, but civic progress and public health demand that the system chosen be the most efficient that can be installed under those conditions.

The systems named below can, with proper care and usage, be considered safe means of sewage disposal.

OUTFALL SEWERS.

Sewage may be drained by gravity or pumped from a sump into a body of water, as a river, large lake, or bay. This system is feasible only on large rivers, lakes, or bays where the stream flow or body of water is sufficient to afford great dilution and rapid disintegration. Sewage should never be permitted to flow into small streams from which water for domestic purposes is taken at points downstream.

SEPTIC TANKS.

In the septic-tank system the sewage goes to settling tanks large enough to retain the entire flow for 12 to 24 hours. These tanks are usually built below the surface and are covered except for ventilating manholes. In these tanks the solid part of the sewage disintegrates and part of the organic matter is liquified and gassified by bacterial action. This process, called digestion, reduces about 40 per cent of the solid matter; the remainder settles to the bottom as sludge, which is removed and burned or buried at intervals of six months to two years, according to the rate of accumulation. The effluent from the tanks is entirely liquid and, although not sterile, it is so different from the original sewage that its disposal by surface dissipation over sand or gravel beds is not objectionable.

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BROAD IRRIGATION.

In broad irrigation the crude sewage is applied to land or is run to specially prepared beds of coke and gravel. This method is applicable only where the soil is porous and its maintenance demands care; it is much more liable to pollute water supplies and to create stenches than is the use of septic tanks.

Combinations of the septic-tank and broad irrigation give excellent results.

CESSPOOLS.

Cesspools are not recognized as safe means of disposal of sewage and should not be tolerated except where conditions make more sanitary disposal impossible.

Every camp should have lines of iron or terra-cotta pipe available to every building, and headings should be provided for readily extending the lines as new structures are erected. Money will be saved by anticipating future growth and planning the sewerage system so that lines may readily be extended to serve all additions to the camp or town site.

HOUSING.

The housing conditions of a camp have a decided bearing on the industry and stability of its inhabitants. Houses should be attractive in appearance and designed for comfort and convenience. They should be standardized in general construction to permit economy in the purchase of material but diversified in external design to afford variety. A camp with row after row of houses constructed on the same plan and identical in appearance is not pleasing to the sight, stifles individualism, and deadens ambition.

The kind of building material selected will accord with convenience, but houses built of cheap material and faulty in construction are not only unsubstantial but always costly in the long run; their maintenance and upkeep over a period of years amounts to more than that of houses properly built. Brick or hollow tile and cement, although usually more expensive than lumber, have the advantages of conforming better to standardization and of affording more permanent construction, with consequent minimum upkeep, reduced fire risks, and economy in heating.

The plans of houses should provide economy of space. Wasted space has a cost proportional to utilized space. Living and sleeping quarters should be large enough and well lighted and ventilated. The number of rooms should accord with the size of the families occupying the houses, in order to avoid overcrowding and satisfy the requirements of wholesome and decent living.

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Every house should be connected with the water and the sewer system, and should have a flushing water-closet. Where possible there should be space for a lawn in front and for a garden in the rear. Special inducements, through a civic organization, to encourage the maintenance of lawns and gardens, will improve the appearance of a town and aid its sanitation.

Boarding houses should be carefully planned with regard to convenience and well-being. The old dormitory type with its large bunk rooms is neither healthy nor conducive to privacy or self-respect. Single rooms or rooms accommodating only two men are much more satisfactory; they should be of ample size, with plenty of window space for light and ventilation. Dining rooms and kitchens should be so situated and constructed as to make their thorough cleaning easy.

DISPOSAL OF HOUSEHOLD WASTES.

Household wastes may be a menace to health; their regular collection and proper disposal is consequently a matter of grave concern to every community. These wastes consist of garbage, ashes, and miscellaneous refuse such as cans, bottles, paper, and general trash. In large communities the separation of the garbage from the other wastes is necessary for proper disposal, but in small communities separation is not required. Garbage, however, is subject to fermentation, evolves unwholesome stenches, and affords breeding places for flies and bacteria; hence until it is collected it should be stored on the premises in separate, water-tight, metal containers with tight-fitting lids. Collection should be regular and at least twice a week. Householders should be required by sanitary regulations to keep premises free from accumulations of refuse. Such regulations if enforced and an effective system of collection and disposal will increase community health and civic pride.

Methods of disposal differ in practicability and efficiency, but where fuel is plentiful and cheap, incineration of all collectible refuse is by far the most sanitary. In oil-shale communities incineration should be adopted because of the availability and cheapness of fuel. An incinerating plant is not expensive to construct and its maintenance should cost little more than the proper care of a municipal dump.

Neglect of the collection and disposal of refuse reacts not only on the community but also upon the industry it serves. Piles of cans and filth dotted over the confines of a camp or town are not only unsightly but they promote a spirit of carelessness and indifference which is reflected in the daily work of the employees.

No camp or town should fail to have a sanitary code covering the usual class of nuisances. This code should be rigidly enforced.

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Whenever people are brought together to live in a confined area there are always some who value their health and the health of their fellow citizens enough to observe proper safeguards. Unfortunately, there are others who fail to realize the dangers of unwholesome and insanitary conditions and they, in proportion to their number, menace the health of the community and make sanitary codes necessary. Enforcement should be vested in an experienced and responsible person who should be held to strict accountability for the general sanitary condition of the camp or town.

ECONOMIC RELATION OF SANITATION TO INDUSTRY.

Efficiency is the foundation upon which success and progress in industry are built; it is not only necessary in the supervision and direction of a successful industry but must pervade the working force. It does not grow spontaneously, but is attracted, engendered, and developed. Men who can be molded into efficient parts of an industry are those who are intelligent and discriminating; such men desire living conditions that are wholesome and sanitary. Thus the character of the community connected with an industry becomes a deciding factor in the class of labor that seeks employment and remains with the industry. Where housing conditions are not good, sanitary conditions are below standard, the moral tone is lax, and the best type of labor is not attracted. Such conditions are tolerated only by the "floater," who is usually shiftless, irresponsible, and unstable.

The sanitary conditions of a camp, besides helping to determine the class of labor seeking employment, are also important in reducing loss of time through preventable illness. The time loss from illness averages 9 days yearly per employee, or 900 days (nearly 2½ years) per 100 employees. A considerable part of this illness is preventable.

The principal agencies through which preventable diseases are controlled and needless time loss is prevented are adequate space, dryness, light, ventilation, house-heating facilities, purity and sufficiency of water supply, safe disposal of sewage, care and cleanliness in the storage and handling of food, and systematic collection of refuse in which bacteria and disease-carrying flies may breed. To the employer time loss represents a waste through lessened production; to the employee it represents a double waste through loss of wages and the cost of medical attention.

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